GLEN AND GRAND CANYON

RIPARIAN RESTORATION PROJECT:

FINAL REPORT FOR ARIZONA WATER PROTECTION FUND

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INTRODUCTION

Riparian Restoration in Glen and Grand Canyons

The Arizona Water Protection Fund (AWPF) awarded a grant to Grand Canyon Wildlands Council, Inc. to collaboratively conduct a multi-phase, multi-year riparian restoration project with the National Park Service (NPS) in Glen Canyon National Recreation Area (GCNRA) and Grand Canyon National Park (GCNP), focusing on tamarisk (saltcedar, *Tamarix ramosissima*) control. The project was conceived in response to conservation concerns about the dominance of tamarisk on upper riparian terraces at Lees Ferry, one of about a dozen sites along the Colorado River mainstem in Grand Canyon historically documented as formerly occupied by cottonwood/willow stands. The proposal included restoring a 10-acre site at Lees Ferry. The project was also intended to reverse the continuing expansion of tamarisk into many of the nearly pristine tributaries downstream in GCNP, Arizona. GCNP, GCNRA, the U.S. Fish and Wildlife Service (USFWS), the Arizona Game and Fish Department (AGFD), Grand Canyon Trust, and the Arizona Native Plant Society all endorsed this project. This report documents the work performed and the project accomplishments from 2000-2004 by the project team: Grand Canyon Wildlands Council, the GCNP Science Center, Fred Phillips Consulting, other collaborators and numerous volunteers.

In the Southwest, riparian areas account for less than 1% of the land, yet over 65% of southwestern wildlife depends on riparian habitats. Distinctive soil types, vegetation, and hydrologic conditions characterize riparian areas, which contain biologically diverse ecosystems. These habitats are among the most productive, most valuable and most threatened habitats in the American Southwest (Johnson et al. 1985). Desert seeps and springs likewise are highly productive and biologically diverse, commonly hosting 100- to 500-fold higher concentrations of species than the surrounding desert landscapes (Grand Canyon Wildlands Council 2002, 2003). Southwestern seeps and springs are often isolated islands of habitat that support an unusual proportion of relict and endemic species, contributing significantly to regional biodiversity. Perennial tributaries, seeps, and springs also provide habitat for many of the obligate wetland species, and within Grand Canyon, including four endemic plant species: Kaibab sedge (*Carex curatorum*), Navajo sedge (*C. specuicola*), an undescribed thistle (*Cirsium* sp.), and McDougall's yellowtops (*Flaveria mcdougallii;* Spence 2002).

Deciduous, pentamerous tamarisk is a small, exotic tree introduced to the Southwest near the turn of the century from southern Eurasia (Horton 1977; Baum 1978). Tamarisk, now a dominant riparian shrubby tree in the Colorado River basin below 2,000 meter (m) elevation, spread rapidly throughout the system via wind-dispersed seeds (Graf 1978). Tamarisk had reached the Grand Canyon by 1938 (Clover and Jotter 1944) and the oldest trees found in the system thus far, date to about 1935 (R. Hereford, U.S. Geological Survey, Flagstaff, Arizona, personal communication). Tamarisk occupied pre-dam terraces and tributaries during the pre-dam era, and was the first species to invade the newly stabilized post-dam riparian zone in the Grand Canyon (Turner and Karpiscak 1980).

The impacts caused by tamarisk in the Southwest are well documented (cf. NPS 2002 and Section 3). Tamarisk, like cheatgrass (*Bromus tectorum*) in upland habitats, increases fire frequency in riparian habitats in the western United States, where fire has not played a strong evolutionary role (Busch et al. 1992). Increased disturbance from fire simplifies those ecosystems. Tamarisk often develops monoculture stands and lowers water tables, which can negatively affect native plant and wildlife communities (Duncan 1996). In many areas, tamarisk occupies previously open spaces and is adapted to a wide range of environmental conditions. Once established in an area, it typically spreads and persists, preempting native plant establishment. Despite the contention that tamarisk increases the salinity of soils, thereby outcompeting native plant species (Brotherson and Field 1987), experiments in Grand Canyon have shown only that deep duff and plant foliar exudate accumulation make it difficult for any seed to germinate beneath tamarisk (see Section 3). A more likely explanation for the success of tamarisk in the Southwest may be that it is more fecund and able to tolerate greater environmental stress than are native species.

Tributaries and side canyons of the Colorado River, as well as seeps and springs in Grand Canyon are among the most pristine watersheds and desert riparian habitats remaining in the coterminous United States. Significantly, the sources of perennial water in the tributaries are often seeps and springs. These riparian systems deserve a high level of protection from exotic plant invasion. The recent encroachment of tamarisk into the tributaries poses a significant threat to the ecological integrity of these natural ecosystems.

Lees Ferry, in Glen Canyon National Recreation Area, is a major recreation hub for river runners, naturalists, sports fishermen, backpackers and boaters. Lees Ferry is located at the transition between Glen (GCNRA) and Marble (GCNP) Canyons, areas that support over 400 species of birds, fish, mammals, amphibians and reptiles including the endangered southwestern willow flycatcher. By 1975 the floodplain at Lees Ferry had become completely infested with tamarisk. The invasion of tamarisk at Lees Ferry led to a decline in native cottonwoods, willows and various riparian shrubs on which native birds and other wildlife depend.

GCNP and the GCNRA are committed to the preservation of native plant communities and native ecosystems (NPS 1995a, NPS 1995b). NPS management policies require park managers "to maintain all the components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2001b). Park managers are directed to give high priority to the control and management of exotic species that can be easily managed and have substantial impacts on the Park's resources (NPS 1985, NPS 2001b). The central mission of Grand Canyon Wildlands Council is to create and apply a dynamic conservation area network that ensures the existence, health, and sustainability of all native species and natural ecosystems in the Grand Canyon ecoregion, with a primary goal of restoring natural processes.

The Glen and Grand Canyon riparian restoration effort helps preserve riparian habitat, encourages ecosystem sustainability, promotes native plant community recovery, and moves forward the central missions and policies of the NPS and Grand Canyon Wildlands Council. The two elements of this work also test and document the effectiveness of various approaches to tamarisk removal. This effort is also an excellent example of successful collaboration between federal, state, and non-governmental organizations on ecosystem restoration. The site at Lees Ferry is effectively a pilot project for demonstrating the potential success of site-specific riparian restoration along the Colorado River mainstem in the Grand Canyon region.

Project Objectives and Work

The Glen and Grand Canyon Riparian Restoration Project has three primary objectives:

1) To synthesize existing information on the ecology and control of tamarisk.
2) To transform a well-established 10-acre tamarisk stand at Lees Ferry back into riparian habitat dominated by native Fremont cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), and other native phreatophytes. This Glen Canyon

component, designed as a pilot effort, was accomplished by site and resource assessment; selective clearing of tamarisk; pre-treatment soil analyses; drip irrigation; native plant species propagation and transplanting; hole augering, planting, and irrigation; plant monitoring; and pre-, during- and post-treatment monitoring of avifauna. The Lees Ferry site is accessible and previously disturbed, which makes it a good location for testing and demonstrating the effectiveness of restoration techniques along the mainstem of the Colorado River.

3) To help the NPS in Grand Canyon meet its administrative goal to manage away from non-native species. This project proposed to reverse tamarisk invasion in 63 tributaries in Grand Canyon by mechanical removal practices compatible with wilderness management, along with the application of Garlon herbicide. Most of the tributaries that lie wholly within the park still have relatively low population densities of this non-native.

At Lees Ferry, Fred Phillips Consulting, with Grand Canyon Wildlands Council, tested the soils and water table depths on site and generated a site revegetation plan. After this we cleared the site of tamarisk. The revegetation and monitoring process began in the summer of 2001. Project team members planted approximately 950 native plants. The majority of the new plants comprised Fremont cottonwood, four-wing saltbush and three different species of native willows but the plantings also included netleaf hackberry seedlings as well as shrub live-oak, single leaf ash, box elder, desert olive, greasewood, apache plume and squawbush.

The tributary work involved NEPA compliance (GCNP 2002), pre-treatment assessment of site conditions and avifauna, tamarisk removal and herbicide (Garlon) application, and post-treatment monitoring of tamarisk demography and any native plant establishment. Prior to conducting any tamarisk eradication in tributaries GCNP and Grand Canyon Wildlands surveyed for sensitive species, including Kanab ambersnail, northern leopard frog, spadefoot toad (which may occur in the Lees Ferry area and in Chuar drainage at Mile 65R) in cooperation with the USFWS and AGFD. Control efforts were limited by agreement to not conduct treatments in the vicinity of potential habitat of endangered southwestern willow flycatcher (WIFL; *Empidonax trailii extimus*), or in the Little Colorado River, where tamarisk is considered to provide habitat for endangered humpback chub (*Gila cypha*).

By removing tamarisk from these tributaries, GCNP and Grand Canyon Wildlands have substantially set back the invasion process by 50+ years, and thereby preserved the otherwise pristine character of these drainages. We recognized that flash floods and debris flows in the tributaries may slow tamarisk re-invasion to the extent that it could be held in check in the future with only periodic site visits. If the proposed actions had not been undertaken, it was likely that a critical threshold population of tamarisk could be reached in these tributaries, beyond which population expansion would greatly increase, making control exponentially more costly in the coming decades.

Budget and Project Administration

The AWPF budget for this project was $371,285, supplemented by an additional $146,720 in matching funds and in-kind services from collaborators. Grand Canyon Wildlands Council managed the project with the administrative assistance of Fred Phillips Consulting, and regular reports were submitted throughout the 4-year project period.

The specific tasks described in the AWPF contract and reported here were:

Section 1	Task #1: Permits, Clearances, & Authorities
Section 2	Task #2: Establish Project Administrator
Section 3	Task #3: Complete Database and Evaluate Tamarisk Ecology
Section 4	Task #4: Preparation of Monitoring, Revegetation, and Photo Monitoring Plans
Section 5	Task #5: Conduct Pre-Revegetation Avian Censusing at Lees Ferry
Section 6	Task #6: Pre-Tamarisk Eradication Monitoring in the Colorado River Tributaries
Section 7	Task #7: Revegetate at Lees Ferry
Section 7	Task #8: Monitor at Lees Ferry
Section 8	Task #10: Post Revegetation Avian Census
Section 9	Task #9, 11: Tamarisk Eradication and Post Tamarisk Eradication Monitoring along the Colorado River Tributaries

Acknowledgements

Grand Canyon Wildlands Council, the Grand Canyon National Park Science Center, and Fred Phillips Consulting gratefully acknowledge the support of the Arizona Department of Water Resources, Arizona Water Protection Fund who made this work possible. In particular, we thank Reuben Téran, our dedicated project manager and Colorado River enthusiast. In addition we thank AWPF staff Rodney Held, Perri Benemelis, Lisa Swanson, and especially former project manager Selinda Border and Dave Christiana (veteran of the rain-drenched lower half of the October 2000 river trip) for assistance during the project. Lori Makarick of GCNP is especially commended for actively serving for five full years as the NPS staff lead to the tributary restoration work, and continues to do so. We also greatly appreciate the resource management support of NPS staff Norm Henderson, Jeffrey Cross, John Ritenour, and John Spence. We thank Frank Hays for his efforts during the proposal phase and for his save-the-day cameo as shuttle driver on the May 2004 trip. Richard Clark of Vermillion Cliffs diligently watered, weeded, and fenced hundreds of young native plants at Lees Ferry, for which we heartily thank him, along with the Glen Canyon NRA Lees Ferry staff. Arizona Raft Adventures, Arizona River Runners, and Canyon Explorations fully and/or partially outfitted river trips and Professional River Outfitters and Moenkopi Riverworks provided discounted rentals of river gear. We thank Jeri Ledbetter, Brad Dimock, Monte Tillinghast and Yellow Jacket River Guides for additional donations of river gear and shuttle vehicles. Professional photographers David Edwards, Rachael Running, Scott Smith, and Kathryn Thompson provided some of the pictures; and Jeri Ledbetter took video. Most of all we are grateful to the numerous river crew and volunteers, who hacked, huffed, sweated, and smiled through the removal of more than 70,000 tamarisk trees, saplings, and seedlings.

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SECTION 1: PERMITS, CLEARANCES, & AUTHORITIES

All permits, clearances, and authorities were obtained and submitted to AWPF. These documents are on file at AWPF and at the Grand Canyon Wildlands Council office. The Glen Canyon National Recreation Area Lees Ferry revegetation work moved forward under Categorical Exclusion as a pilot project in a previously disturbed and culturally surveyed site. Public scoping and interdisciplinary team discussions about tamarisk management in Grand Canyon National Park were ongoing from 1998-2002. The NPS issued the Environmental Assessment/Assessment of Effect for the tributary tamarisk eradication portion of the project to the public in February 2002. Staff received and analyzed public comments, and prepared a Finding of No Significant Impact Statement (FONSI), signed by the regional office on June 18, 2002. The park received a written response to the Informal Consultation with the U.S. Fish and Wildlife Service (USFWS) on January 25, 2001 and that letter, along with the incorporation of their recommended changes, completed the Section 7 consultation that was necessary for this project. On April 8, 2002, the State Historic Preservation Officer (SHPO) provided the park with written concurrence on tributary eradication of tamarisk moving forward.

SECTION 2: PROJECT ADMINISTRATOR

Fred Phillips Consulting completed work as project administrator, assisting Grand Canyon Wildlands in tracking budgets for specific tasks and coordinating the work effort with collaborators.

SECTION 3: SYNTHESIS OF SALTCEDAR ECOLOGY, MANAGEMENT, AND CONTROL

By Lawrence E. Stevens, PhD

Executive Summary

Grand Canyon Wildlands Council synthesized existing information on the ecology, management and control of non-native saltcedar (Tamaricaceae: *Tamarix ramosissima* Deneb.), with particular emphasis on the Grand Canyon region of northern Arizona. This report was prepared in response to a proposal to control saltcedar in the tributaries of the Colorado River in Grand Canyon National Park and to replace a 4 hectare (ha) stand of saltcedar at Lees Ferry with native woody phreatophytic vegetation.

Deciduous, pentamerous saltcedar is a small, exotic tree introduced to the Southwest near the turn of the century from southern Eurasia (Horton 1977; Baum 1978). Saltcedar, now a dominant riparian shrubby tree in the Colorado River basin below 2,000 meter (m) elevation, spread rapidly throughout the system via wind-dispersed seeds (Graf 1978). Although saltcedar had reached the Grand Canyon by 1938 (Clover and Jotter 1944), the oldest trees found in the system thus far, date to about 1935 (R. Hereford, U.S. Geological Survey, Flagstaff, Arizona, personal communication). Saltcedar occupied pre-dam terraces and tributaries during the pre-dam era, and was the first species to invade the newly stabilized post-dam riparian zone in the Grand Canyon (Turner and Karpiscak 1980).

Mature saltcedar plants are capable of producing 2.5 x 10^8 tiny, wind-dispersed seeds per year (Stevens and Waring 1988). Its seeds are short-lived (less than 2 months in summer), have no dormancy requirements, and germinate in less than 24 hours (h) (Stevens 1989b). Saltcedar seeds require a moist, fine-grained (silt or smaller particle size) substrate for eccesis, such as is found in southwestern riparian habitats after floodwaters subside (Stevens 1989a,b, Warren and Turner 1975). Saltcedar commonly co-occurs with *Populus fremontii*, *Salix exigua*, *Salix gooddingii*, and *Tessaria sericea* (Marks 1950; Stevens, in press), but the non-native species is more tolerant of harsh environmental extremes than are native species (Warren and Turner 1975; Stevens and Waring 1985).

Saltcedar has a rather deep (approximately 1 m) root crown, from which it resprouts after damage or loss of above ground growth (i.e., from fire, flood or herbivory); however, >25 yr of observation of saltcedar in Grand Canyon has failed to reveal any sprouting or vegetation reproduction from running (or any) roots (Stevens and Ayers 1993; L.E. Stevens, Grand Canyon Wildlands Council, Flagstaff, AZ). Saltcedar actively develops adventitious roots when inundated for long periods, and can "terrace." This is a process in which branches connected to the main trunk that are buried, develop adventitious roots and sprout new above-ground stems; however, terraced branches fail to develop as independent plants and generally fail after <3 yr in Grand Canyon.

Saltcedar's success in riparian environments in the Southwest appears to be a function of its extraordinary seed production and its greater drought and flood tolerance, as compared to its most common co-occurring native analogue, *Salix exigua* (Warren and Turner 1975; Stevens and Waring 1985). In an effort to understand the ecological success of saltcedar, experiments on its competitive ability, germination and nutritional requirements, and other aspects of its life history were conducted (Stevens 1989a). Competition experiments with *Salix exigua*, a common neighbor throughout the Colorado River system, failed to demonstrate competitive superiority of saltcedar over the willow. In fact, at the seedling stage, willow was competitively dominant.

Saltcedar was consumed by several introduced invertebrate herbivores, particularly the cicadellid leafhopper, *Opsius stactogalus*; however, invertebrate herbivore standing crop was equivalent with *Salix exigua* during normal (non-flooding) years in the Grand Canyon (Stevens 1985). Saltcedar was more drought tolerant and inundation tolerant than any native species. Some saltcedar survived more than two yr of root-crown inundation in the Grand Canyon during high water events from 1983-85 (Stevens and Waring 1988), a period far exceeding the 90 day (d) record observed in warm, anoxic reservoir waters observed by Warren and Turner (1975). Saltcedar is extraordinary not only in its persistence, but also in its reproductive output, as mentioned, and seedling densities in excess of 15,000/meter squared (m^2) have been observed in the southwest (Warren and Turner 1975; R.M. Turner, U.S. Geological Survey, Tucson, Arizona, personal communication). These life history characteristics make saltcedar highly successful in the harsh, unpredictable channels of unregulated southwestern rivers, but limit its recruitment along the more stabilized channels of regulated streams.

Saltcedar management is influenced by legal designation of selected southwestern riparian areas as critical habitat for endangered southwestern willow flycatcher (*Empidonax trailii extimus*). In Grand Canyon, the portion of the mainstream between Miles 46 and 72 is designated as critical habitat, and is not to be adversely affected by federal management actions. However, tributaries and the Lees Ferry area are not presently designated as critical habitat. The National Park Service mandate includes management for the natural (presettlement) condition, and management away from non-native species. Grand Canyon National Park and Glen Canyon National Recreation Area prepared an Environmental Assessment and a Categorical Exclusion in compliance with National Environmental Policy Act requirements to control saltcedar in 63 tributaries and in a 4 ha pilot stand on the mainstream at Lees Ferry, respectively.

Saltcedar's deep root crown greatly protects the plant from mortality by above ground disturbances, and makes control problematic. Control of saltcedar has been widely assessed, and many methods have been attempted, including cutting, fire, electrocution, hot wax treatment, biological control, mechanical removal, and herbicide treatment (Kunzman et al. 1989). The latter two techniques have proven most effective in saltcedar control efforts, and were used in Grand Canyon. We provide a detailed discussion of the rationale, history, methods, and success rates for these methods from previous efforts.

The introduction of non-native species (NNS) has been one of the most devastating human impacts on this planet's ecology, third only behind outright extinction and habitat destruction. Kudzu, *Melaluca*, Brazilian pepper, Russian olive, purple loosestrife, spotted knapweed and other plant species have taken over many of this nation's great ecosystems, reducing ecological complexity and transforming elegant assemblages into less interactive systems that support fewer species. Saltcedar (*Tamarix ramosissima*) and cheatgrass (*Bromus tectorum*) increase fire frequency in riparian and upland habitats in the western United States, where fire has not played a strong evolutionary role (Busch et al. 1992). Increased disturbance from fire simplifies those ecosystems. The introduction of elm, maple and chestnut blights destroy our nation's most prominent deciduous tree populations, and non-native insects like gypsy moth and maple borer further harm our native forests. Whirling disease, Asian tapeworm and other disease organisms are threatening trout and native fish populations in the Southwest. Avian malaria and brown tree snakes are literally eliminating the native bird fauna of Hawaii and the South Pacific. Non-native house sparrows, starlings and pigeons have become the dominant birds in most urban environments, not native birds. Stevens and Ayers (in press) reported that

10.5% of Grand Canyon's plant species are NNS, a proportion equivalent to that of the United Kingdom.

NNS invasions have dire ecological and economic implications: 1) they disrupt the stability of ecological communities, particularly by 2) altering natural disturbance regimes and increasing the rate of ecological change beyond that tolerable by most species; 3) they degrade fish and wildlife habitat quality; 4) NNS destroy economically important populations; 5) they degrade aesthetic values and recreational experience (*e.g*., the invasion of camelthorn and Russian olive along Southwestern rivers; 6) NNS alter landforms (stream channels, etc.); 7) NNS include the transmission of new disease organisms with devasting population consequences; 8) they can strongly affect public health; 9) NNS damages are extremely costly (several billion dollars/year (yr) in the U.S. at present), and 10) control measures require considerable, time-consuming follow-up monitoring, if control is possible at all.

The susceptibility of ecosystems to invasion by NNS is a complex function of interactions among abiotic and biotic factors, introduction history, and invading species autecology (Lonsdale 1999). Although the life history strategies of eruptive NNS have been studied (e.g., Brotherson and Field 1987, Pysek 1995, Holway 1999), many efforts to predict which introduced species will erupt and where eruptions compromise ecosystem integrity have met with limited success (e.g., Noble 1989, Pysek et al. 1995). In part this is because NNS population eruption often occurs irregularly across spatial scales and among habitats and ecosystems within a biome (Horvitz et al. 1998). For example, NNS eruption may be greatly delayed after initial colonization: Kowarik (1995) reported that on average 147 yr elapsed between introduction and eruption of NNS around Brandenburg, Germany, a finding that highlights great uncertainty in forecasting the potential ecological impacts of NNS. In contrast to Elton's (1958) prediction that invasibility should be negatively correlated with diversity, recent studies report spatial scale-dependent and fertility related positive correlations among NNS and native plant species diversity (Wiser et al. 1998, Lonsdale 1999, Stohlgren et al. 1999). These studies provide welcomed insight into habitat invasibility and NNS eruptions, which are among the most significant, long-lasting and complex anthropogenic impacts on the world's ecosystems.

As with all invasions, conquest affects both the vanquished and the conqueror. NNS gradually become "naturalized", or incorporated into the ecosystem, a process that generally occurs over evolutionary time. The sudden arrival of thousands of NNS during the past century has swamped the ecological adjustment capacity of ecosystems in the United States, many of which have been launched off on unknown trajectories towards an unknown future. However, not all NNS invasions have solely negative consequences on native plant and faunal assemblages. NNS may actually increase habitat availability and invertebrate production, and some native vertebrates take advantage of these new resources. In such cases, management policies need to be considered carefully, particularly when the NNS augment habitat for threatened or endangered species.

Since its introduction into the West prior to 1900, saltcedar or deciduous tamarisk (*Tamarix ramosissima*) has expanded to cover nearly 500,000 hectares (ha). This small shrubby phreatophyte tree exists in its natural range in the Mediterranean and southern Asia areas, and is a taxonomically and biologically novel addition to the flora of North America. It is prized as an ornamental species and a source of nectar for bees and other invertebrates during late May and June, when native species are not in bloom. However, it is widely reviled for its aggressive colonization of riparian habitats and reservoir shorelines.

The Colorado River ecosystem between Glen Canyon Dam (GCD) and upper Lake Mead, Arizona, is a unique setting in which to test ideas about river management and the use of adaptive management experiments to help resolve scientific uncertainties about best management practices (Adler 1996; Bureau of Reclamation 1995; Collier et al 1997; NRC 1996; Schmidt et al. 1998). The river is bounded upstream by Glen Canyon Dam, where water regulation for hydropower production results in delivery of cold, clear, and relatively steady flows into the upper canyon. The river ecosystem ends 475 kilometres (km) downstream at Lake Mead. Natural flows (prior to 1963) were violently seasonal, extremely turbid, and highly variable in temperature. Regulated flows have permitted the development of a productive aquatic community in the upper canyon, sustaining a spectacular rainbow trout fishery and seasonally dense avifauna populations, including bald eagle (*Haliaeetus leucocephalus*), other waterbirds, peregrine falcon (*Falco peregrinus anatum*), and endangered neotropical migrant songbirds, such as the southwestern willow flycatcher (*Empidonax tralii extimus*). As water moves through the Grand Canyon, tributary sediment inputs result in progressive increases in turbidity, shutting down the primary production system and resulting in much lower densities of aquatic invertebrates, fishes, and birds.

Grand Canyon Wildlands Council and the National Park Service (NPS) at Glen Canyon National Recreation Area and Grand Canyon National Park conducted a saltcedar control program in Grand Canyon. The Arizona Water Protection Fund provided funding for this project, and it is cost shared with the NPS and Grand Canyon Wildlands. We set out to stall the invasion of saltcedar in 63 tributaries, killing saltcedar by uprooting smaller plants and by applying Garlon® to the freshly cut stems of larger plants. By removing saltcedar from Grand Canyon tributaries, we expect to set back the invasion process there by 50 years or more.

This project has also replaced the saltcedar stand downstream from the launch ramp at Lees Ferry with native cottonwoods, willows and other native species. This site was photographed in pre-dam time, and prior to the arrival of saltcedar in the 1920's-1930's, the area was dominated by native tree species. We have mechanically removed saltcedar, and planted a beaver-protected stand of native trees and shrubs, monitoring plant growth for three years along with changes in the bird community. This aspect of the project was led by Fred Phillips Consulting, who successfully transformed more than 2 km of the lower Colorado River shoreline near Parker into native cottonwood and willow stands (Phillips 1998). The Lees Ferry revegetation effort is an important pilot study, in that it provides the opportunity to evaluate how to transform saltcedar stands into native vegetation upstream in Glen Canyon, and eventually downstream in Grand Canyon once the administrative challenges are overcome.

In this synthesis we examine the ecology and management of saltcedar, the reasons for its success as a non-native invader, and the unusual case along the mainstream Colorado River in Glen and Grand canyons in which this non-native tree appears to be failing to recruit (saltcedar is actively recruiting in unregulated tributaries in Grand Canyon). In addition, we discuss administrative constraints on saltcedar control related to its inclusion as federally designated critical habitat for endangered southwestern willow flycatcher and other Neotropical migrant birds. We conclude with a history and description of control methods used to manage this invasive non-native species.

The Ecology and Ecological Role of Saltcedar, with Emphasis on the Grand Canyon Region

INTRODUCTION

Saltcedar or deciduous tamarisk (Tamaricaceae: *Tamarix ramosissima* Deneb.) is a widespread exotic phreatophyte introduced to the United States from southern Eurasia as early as 1823 (Bowser 1957; Robinson 1965; Baum 1967; Horton 1977). Two of the 54 species in the family Tamaricaceae were widely introduced to the United States: the anthel (*Tamarix aphylla*) and the deciduous saltcedar (variously identified as *T. gallica, T. pentandra* Pall., *T. chinensis* Loueiro, or *T. ramosissima* Deneb.). The latter species was introduced for ornamental and erosion control purposes (Brotherson and Van Winlel 1986) and occasionally as a windbreak species (Read 1964). Because of its great reproductive rates and stress tolerance, saltcedar escaped cultivation after 1870 and became a significant pest species in naturally and anthropogenically disturbed riparian habitats (Clover and Jotter 1944; Robinson 1958; Christensen 1962; Horton 1962, 1964; Hayden unpublished 1976; Pottery and Pattison 1976; Graf 1978). Today saltcedar occupies more than 500,000 hectares (ha) of riparian land in the western United States (Robinson 1965), including reservoir deltas and shorelines, riverbanks, springs, roadbanks and ditches.

Selected aspects of the saltcedar autecology have been studied (Merkle and Hopkins 1957, Tomanek and Ziegler 1962, Savchenko 1975, Warren and Turner 1975, Brotherson and Field 1987), including the extent to which this species has become incorporated into natural riparian ecosystems (Watts 1973; Orazmukhommedov and Gudkova 1981; Stevens 1976b, 1985; Brotherson and Field 1986; Brotherson and Von Winkel 1987; and Brown 1987). Largely regarded as an invasive, water-consumptive phreatophyte, most studies have been concerned with saltcedar distribution (Robinson 1952, 1958, 1965; Skinners 1957; Harris 1966; Baum 1967; Haase 1972; Turner 1974; Vasil'chenko and Vasil'eva 1976; Turner and Karpiscak 1980; Swenson et al. 1982; De Martis et al. 1984, 1986), taxonomy (Dodge 1951; Horton 1962; Baum 1967, 1978; Qaiser 1981) and control or erradication (Frost and Hamilton 1960; Cords and Bodiei 1964; Hughes 1965, 1966, 1968; Brooks 1971; Davenport 1978, 1982a,b; Engel-Wilson and Ohmart 1978; Cohen et al. 1978; Hollingsworth 1969, 1978; Hollingsworth et al. 1979; Wilkinson 1980; Anderson and Ohmart 1982; Ohmart and Rinne 1982; Howard et al. 1983; Neill 1983; Pemberton 1985; Johnson 1986), including biological control (Gerling and Kugler 1973, 1976; Habib et al. 1976; Kunzman et al. 1989). Control-oriented studies generally reported that manual removal or burning were costly and/or ineffective means of eliminating saltcedar, and that combination treatments programs (e.g., fire and individual applications of systemic herbicides or transpiration retardants) were needed. Several studies have been devoted to propagation techniques for saltcedar (Wilkinson 1966c; Ando 1980; Liu 1984), because it is commonly used as a windbreak (Read 1964; Brooks and Dellberg 1969).

Physiological studies of saltcedar have concentrated on water relations (Decker and Wein 1960; Decker et al. 1962; McDonald and Hughes 1968; Mace 1971; Wilkinson 1972; Davenport et al. 1978; Gay and Fritchen 1979; Van Hylckama 1980; Anderson 1982; Weaver 1984), leaf morphology (Zhai et al. 1983), leaf physiology (Wilkinson 1966a; Davenport et al. 1978), growth of adventitious roots (Wilkinson 1966b), general growth (Hughes 1967; Wilkinson 1966d), salt tolerance (Waisel 1961; Mark and Peterson 1962), salt physiology (Decker 1961; Hem 1967; Berry 1970; Kleinkopf and Wallace 1974), and water uptake (Busch et al. 1992). Field salinity levels in soils supporting saltcedar in the Grand Canyon ranged from 20 to 50 ppm at the river's edge to 500 or more than 1,000 ppm in pre-dam terraces (Stevens and Waring 1987), while salinity levels in soil supporting saltcedar growth Death Valley exceed 50,000 ppm (Hem 1967).

Some attention has been devoted to seed characteristics, germination requirements (Horton et al. 1960; Waren and Turner 1975; Brock unpublished 1984) and plant architecture (Merkel and Hopkins 1957; Gary 1963; Gary and Horton 1965; Wilkinson 1966b). Little attention has been devoted to the secondary chemistry of saltcedar, although the presence of flavonoid bisulphates has been documented in the genus (Harborne 1975; Nawar 1977) and the effects of pollutants were considered in one study (Dreesen and Wangen 1981). Ecotypic variation in saltcedar has been studied by Matyushenko et al. (1977) in Kazakn, USSR and by Wilkinson (1980) in the United States.

Saltcedar seed production phenology was examined by Warren and Turner (1975) and Waring and Stevens (1987). The former study reported a bimodal pattern of seed release at low elevation in central Arizona, with peak seed abundance in May and August. The latter study, conducted among water-stressed plants growing near Lees Ferry, Arizona, focused on plants that grew on upper river terraces. Waring and Stevens (1987) reported a single, large peak of flowering in May, with minor levels of blooming occurring throughout the growing season.

Baum et al. (1971), Baum (1978) and Lewis et al. (1983) described saltcedar pollen morphology and wind transport capability, and Markgraf (University of Arizona Pollen Laboratory, Tucson, AZ, written communication) concluded that saltcedar pollen was too large to be readily wind transported. Saltcedar gametogenesis was examined by Nesty (1974).

Saltcedar germination required less than 24 hours (Horton et al. 1960; Warren and Turner 1975) and saltcedar seedlings required moist, fine sediments for establishment. Such conditions were commonly found along unregulated southwestern rivers after floods subsided (Stevens and Waring 1985) and at the heads of reservoirs during summer drawdown (Warren and Turner 1975). Saltcedar seedlings were found to be extremely small and grew slowly as compared to other riparian woody perennials (Waring and Stevens 1987). Susceptibility to scouring removal by fluctuating water levels was found to decrease significantly during the first six months of growth (Warren and Turner 1975; Waring and Stevens 1987).

Flooding effects on southwestern riparian plant communities dominated by saltcedar were examined by Campbell and Dick-Peddie (1964), Warren and Turner (1975), Irvine and West (1979), and Stevens and Waring (1985). Saltcedar has been found to be one of the most inundation tolerant riparian plant species in the Southwest, capable of withstanding full inundation in warm, anoxic reservoir waters for more than 3 months (Warren and Turner 1975) and inundation of the root crown in cold, well-oxygenated river water for as long as three years (Waring and Stevens 1987). Saltcedar growth patterns have been useful in determining sedimentation patterns in several tributaries of the Colorado River (R. Hereford 1984).

Campbell and Dick-Peddie (1964), Carothers et al. (1979), Irvine and West (1979), Potter and Pattison (1979), and Carman and Brotherson (1982) found that saltcedar generally occupied flood-prone river margins. Habitat preferences (Carman and Brotherson, 1982; Brotherson and Von Winkel 1986) have been difficult to identify for this generalist species, and demographic studies (Hayden unpublished 1976; Brotherson et al. 1984) have been hampered by this species' phenotypic variability in growth/age relationships and the short period of time it has been present in the Southwest; however, growth rings in saltcedar were considered by Ferguson (University of Arizona Tree Ring Lab, Tucson, Arizona, personal communication) to be annular.

The author (unpublished data) compared relative importance values (Brower and Zar 1984) for saltcedar across a disturbance gradient in perennially wet and ephemeral (dry) tributaries and river corridor riparian vegetation in the Grand Canyon in 1987. He found that saltcedar strongly dominated the Colorado River corridor but was of little significance in the unregulated tributaries. Saltcedar dominated the streamside zone where both moisture and disburance are high, and its importance values declined with distance away from the stream channel.

Despite rather high survival and germination rates following flooding, saltcedar recruitment was minimal for saltcedar in the coarse, post-1984 beach sands in the Grand Canyon, while rapid invasion of these beach substrates was noted by clonal plant species (e.g. *Salix exigua, Alhagi camelorum, Aster spinosus* and *Tessaria sericea*; Stevens and Waring 1985; Waring and Stevens 1987). Saltcedar was shown to be one of the slowest growing riparian species during the critical first month of growth, as compared to native riparian perennials, and saltcedar growth was significantly reduced in nutrient depleted post-dam beach soils (Waring and Stevens 1987). Thus dam-induced edaphic changes in the Grand Canyon appear to have limited saltcedar recruitment.

Saltcedar in the Grand Canyon bloomed abundantly at the beginning of June when few other flowers were available for pollinators (Stevens 1976b). The importance of this resource for invertebrates using saltcedar flowers (Thysanoptera, Coleoptera, some Lepidoptera, Diptera, and Hymenoptera) must be great but has yet to be examined; however, *Frankliniella occidentalis* (Thripidae) can become a biting pest to humans along the Colorado River after saltcedar flowering ceases. Saltcedar has been claimed a valuable source of nectar for honey bees (Watts et al. 1977; Pemberton 1975), and honey bees commonly attended saltcedar flowers (Stevens 1976a), but the value of saltcedar honey is low because of its rank taste (Dr. J. States, apiarist, Northern Arizona University, Flagstaff, Arizona, personal communication).

The invertebrate herbivore fauna associated with saltcedar has been studied in its homeland where saltcedar is attacked by several hundred herbivore species (Gerling and Kugler 1973; Zocchi 1970; Ghani and Mohyuddin 1982; Fedetova 1983; Habib et al. 1976; Habib 1983). Invertebrates associated with saltcedar have also received considerable attention in the United States (Hefley 1937; Bibby 1942; Hopkins and Carruth 1954; Liesner 1971; Gerling and Kugler 1976; Stevens 1976a, b, 1985; Watts et al. 1977; Glinski and Ohmart 1984; Waring and Stevens 1987). Saltcedar is a chemically and architecturally well-defended species, and its attendent invertebrate herbivore fauna is primarily comprised of two exotic species, the saltcedar leaf-hopper, *Opsius stactogalus* Fieber, and a diaspidid scale, *Chionaspis etrusca* Leonardi, both of Middle Eastern origin (Stevens 1985). The saltcedar leaf-hopper has received some ecological attention (Olson 1921; Harding 1930; Liesner 1971). Native invertebrate herbivores were found to include the Shoshone locust (Locustidae: *Schistocerca alutacea shoshone* Scudder), the saltcedar plant bug (Miridae: *Parthenicus* nr. *ruber* Van Duzee), and *Characoma nilotica* (Rogenhofer), a flower-feeding noctuid moth (Stevens 1989b). Although saltcedar in western North America has enjoyed relative freedom from invertebrate herbivory, this ecological release may not be responsible for the success of saltcedar in North America (Stevens 1989a).

Two controversies have arisen concerning the ecology of saltcedar in the United States. Saltcedar has been described as an allelochemically competitive invader of riparian habitat (Brotherson and Field 1987: 110); however, this contention lacks experimental verification. Competition has rarely been demonstrated to be a significant ecological factor determining the success of introduced species (Simberloff 1981), and an equally viable alternate hypothesis regarding the success of saltcedar in the Southwest may be that it is more fecund and better adapted to environmental stress than are native species.

Tamarix ramosissima was one of the first riparian perennial plant species to become widely established in the newly stabilized riparian corridor in the Grand Canyon after construction of Glen

Canyon Dam in 1963, and saltcedar was common by 1973 (Turner and Karpiscak 1980). More recently, native perennials, particularly clonal *Salix exigua* and *Tessaria sericea*, and *Baccharis* spp., have colonized the river corridor (Martin unpublished 1971; Turner and Karpiscak 1980), invading habitats formerly dominated by saltcedar (Brian 1982; Stevens and Waring 1985; Phillips et al. 1977, 1987). The successional replacement of saltcedar by native species in the dam-controlled Grand Canyon is therefore of considerable interest in the debate over the competitive nature of this exotic phreatophyte.

Another ecological controversy involves the ecological value of saltcedar in southwestern riparian communities. Several studies have concluded that saltcedar supported only depauperate avian and invertebrate herbivore faunae (Cohan et al. 1978; Hunter et al. 1985; Johnson 1986), while other studies reported that saltcedar played a valuable ecological role by supporting populations of herbivores and bird life (Beidieman 1971; Stevens 1976a, b; Brush 1983; Brown et al. 1984; Brotherson and Field 1987; Brown 1987; Waring and Stevens 1987; Warren and Schwalbe 1987).

Thus the biology, ecological role and value of saltcedar are poorly understood and have been much debated. In answer to Everitt's (1980) plea, the following study attempted to provide ecological information on saltcedar ecology by addressing salient life history characteristics, population regulation mechanisms and the ecological potential of saltcedar in riparian habitats in northern Arizona.

METHODS OF A SALTCEDAR STUDY IN GRAND CANYON AND AT LEES FERRY

Field and laboratory experiments and measurements were designed to elucidate aspects of saltcedar life history traits, and this species' responses to environmental gradients (light, nutrient and moisture availability), disturbance (flooding and desiccation), predation (herbivory) and competition at several stages in the life of the plant. From 1987-89, field studies were conducted at Lees Ferry, Arizona (elevation 947 m, 3107 ft) and in the Grand Canyon, and laboratory work was conducted at Northern Arizona University in Flagstaff, Arizona (2,073 m, 6,800 ft; Stevens 1989a). Observations on saltcedar flowering phenology and seed production were made on more than 30 mature plants and monitored at 5 week intervals (the life span of an individual raceme) at Lees Ferry. Invertebrate pollinators were excluded from 10 flowering branches to assess entomophily as a pollination strategy.

Numerous experiments and measurements were conducted to assess saltcedar germination requirements under various environmental conditions in the laboratory. For all germination and growth experiments, saltcedar seeds were collected from 15 plants at Lees Ferry, Arizona and mixed thoroughly to simulate a natural seed reservoir. Five replicates of 50 seeds were germinated in solutions with pH from 2.0 to 12.0 at 1.0 pH increments to evaluate optimal pH for germination. To evaluate the impact of salinity on germination, 3 replicates of saltcedar seeds were sown in solutions containing 0.00, 0.01, 0.05, 0.10, 0.50, 1.0 and 2.5 molar (M) NaCl for 10 days at 20^oC (68^oF). Germination rate was evaluated for 10 replicates at 20^oC (68^oF).

A survey of 97 randomly sampled germination sites was conducted in the Grand Canyon by stopping at pre-designated river mileages and searching for the nearest saltcedar seedling. Distance to the nearest canopy adult and the canopy diameter of that mature plant were recorded at each site.

Seedling growth was evaluated under a variety of soil and other environmental conditions. Daily flow fluctuations and post-dam flooding from Glen Canyon Dam produced a strong gradient in soil quality between the riverside beaches and the perched, pre-dam terraces. Waring and Stevens (1987) reported that post-dam beach soil consisted of coarser, nutrient depleted sand, while pre-dam sediments consisted of fine sand/silt with higher nutrient concentrations. This gradient steepened significantly following flooding in 1983-1984, but recent aggradation during moderate, fluctuating flows has improved beach soil conditions. The observation that saltcedar recruitment was limited in coarse beach sand led to many of the following experiments of the factors limiting seedling growth:

1) Seedling growth responses to light intensity were examined by showing saltcedar seeds in 12 liter (3 gal) pots under 6 light regimes (0.65%, 2.82%, 13.70%, 18.0%, 35.5% and 100% ambient light) at Lees Ferry. Light intensity in this experiment was varied using screens; water was applied liberally every 6 hours (hr); fine-pre-dam fluvial soils was the potting medium; and seedlings were grown for 50 d before harvesting.

2) The role of density-dependent growth reduction was assessed by growing saltcedar seedlings in densities of 1, 2, 5, 10, and 20 seedlings/tube in Ray Leach™ tubes in fine, field-collected riparian soil. Tubes were harvested after 90 d and seedlings were dried and weighed.

3) To assess the role of soil nutrient status on seedling growth, a mix of seeds from 10 plants was collected in the field and transferred one each to 3.5 x 35 cm (1.4 x 14.0 in) glass tubes containing either nutrient rich pre-dam soil or nutrient poor post-dam soil from Lees Ferry. Seedlings were gently flushed from the tubes after one month of growth, dried, and weighed.

4) Single and multiple nutrient additions were made to post-dam Colorado River corridor soils from the Grand Canyon to determine if nutrients limited saltcedar growth and, if so, which nutrients are most important. Eight day old saltcedar seedlings in nutrient-poor, field-collected soil received 10 milliliter (ml)/d (0.36 oz/d) of 0.001M N (as nitrate, K, P, NP, NK, PK, NPK, Fe, micronutrients; 0.01 M, 0.05 M, 0.10 M NaCl; while the 2 groups of control plants received a complete 20% hydroponic soloution or just deionized water. The hydroponic solution consisted of 1.0 ml (0.04 oz) 1M $Ca(NO_3)_2$ + 1.0 ml 1M KNO_3 + 0.4 ml $MgSO_4$ + 0.2 ml 1M KH_2PO_4 + 0.2 ml 1M FeEDTA + 0.2 O ml micronutrient solution brought to 1 liter (1.0 qt) volume with deionized H_2O (Kaufman et al. 1975: 130). Nutrient solutions were delivered in daily water treatments to assure continuous nutrient availability.

5) The effects of NaCl concentrations were assayed by daily watering saltcedar seedlings with 0.0 M, 0.001 M, 0.005 M, 0.01 M, 0.05 M, 0.10 M, 0.50 M, 1.00 M and 2.50 M NaCl concentrations grown one each in Ray Leach™ tubes in post-dam beach soil. To corroborate these nutrient addition results, 10 ml/d (0.4 oz/d) of 100% Kaufman et al. (1975: 130) nutrient solution lacking one essential nutrient (either N, P, K, Fe or micronutrients) were provided 15 replicates of saltcedar seedlings for 30 days. The two controls (distilled H_2O and complete 20% Kaufmann et al. hydroponic solutions) were run for all nutrient experiments to define the total range of growth for saltcedar seedlings. Light was provided by white fluorescent light. Fourteen to 21 seedlings were grown in each treatment for 30 days and then harvested, dried and weighed.

6) A laboratory experiment was employed to determine the relative importance of nutrient depletion versus reduced water-holding capacity of pre-dam (nutrient rich) versus post-dam (nutrient depleted) soils on saltcedar seedling growth. A 3-factor laboratory experiment was used to distinguish the effects of altered soil texture (decreased moisture retention) and nutrient availability of seedling growth. Two levels of deionized water (low = 10ml/d, and high = 20ml/d; 0.4 oz/d to 0.7

oz/d) and three levels of nutrients (low, medium and high) and were administered to saltcedar and coyote willow seedlings grown one each in 350 ml (0.35 qt) pots filled with field-collected, post-dam soil. Coyote willow was selected for comparison with saltcedar because the two species commonly co-occur across a wide elevational gradient in the Southwest. The low water treatment of 10ml/day (0.4 oz/d) was selected based on previous laboratory assessment of evaporation rates of post-dam soil in that pot type, with less than 10ml water/d resulting in seedling mortality. The high nutrient dosage was full strength Kaufmann et al (1975) hydroponic solution. The medium concentration nutrient solution was one half of the full strength concentration, and the low nutrient treatment was just deionized water. Seedlings were germinated for 7 days and ten replicates of each treatment were maintained for 30 days, harvested, dried and weighed.

To determine the responses of mature saltcedar to variation in light, water and soil quality, a 4-factor experiment was conducted at an open-air nursery at Lees Ferry, Arizona. Two year old saltcedar saplings and two year old coyote willow cuttings were collected in the Grand Canyon and were grown in 12 liter (3 gal) pots for one year. Experimental plants were grown under 3 levels of light, 3 levels of water, and 3 levels of soil texture. Light levels were 100%, 31% and 4% ambient light; water treatments were 0.25 l/d (Qt/d), 0.5 l/d and complete inundation of the soil (1.0 l/d); and soil texture consisted of 6 liters (1.5 gal) of pre-dam soil, 6 l of post-dam soil, or 6 l of a 1:1 mixture of the two naturally occurring soil types. Four replicates of the 27 possible treatments (3 light levels x 3 water levels x 3 soil textures) for each species were grown for one year and then harvested.

Reproductive output of mature saltcedar plants was estimated in the field by counting the number of racemes on 50 marked, mature saltcedar plants at Lees Ferry. Mature plants were selected in an unbiased fashion at 25 m (82 ft) intervals along a transect near the mouth of the Paria River, and raceme counts were made at 5 week intervals (the approximate life span of a raceme). At each collecting period, 10-15 racemes were collected from each reproductive plant, and the number of flowers were counted on each of these racemes. A subsample of 20 flowers were counted on each of these microscopically to determine the mean number of seeds/flower. Total seed production was then calculated for each of the 50 plants.

The ecological dominance of saltcedar was examined in natural and regulated discharge settings in Grand Canyon riparian habitats. Data were compiled from 114 vegetation transects in the river corridor and more than 90 tributaries in 1987. The relative importance of saltcedar (RI_s) was calculated by modifying the importance value formula of Brower and Zar (1984: 91):

$$RI_s = (RD_s + RC_s + RF_s)/ (RD_\Sigma + RC_\Sigma + RF_\Sigma)$$

where s is saltcedar, RD is the relative density of saltcedar, RC is the relative cover of saltcedar (here measured as basal area), RF is the relative frequency of saltcedar and Σ represents those values for all species combined.

Impacts of herbivores were assessed by: 1) exclusion experiments, 2) spraying saltcedar plants at monthly intervals at one site in the Grand Canyon, and 3) by mechanical defoliation of 0%, 25%, 50%, 75% and 100% of the leaf area of 6 replicates of 2 to 4 year old plants at 3 sites in upper Grand Canyon. Information on the invertebrate and vertebrate herbivores associated with saltcedar in the United States was compiled from Stevens (1976a and b, 1985) and Waring and Stevens (1987).

Competitive interactions between saltcedar and coyote willow (*Salix exigua*) were investigated at 3 life history stages in the following experiments: 1) experimental assessment of allelochemical inhibition of germination of and by saltcedar; 2) intercropping and monocultural sowing of seedling saltcedar and coyote willow in pots to investigate interspecific competitive interactions at the seedling stage at the Lees Ferry nursery and in the laboratory; and 3) replacement and density series experiments between older age-class plants, with 10 replicates with 1 to 6 plants/12 liter (3 gal).

Response variables in all seedling and mature plant growth experiments included several measures of below- and above-ground growth, of which 3 variables were considered to be ecologically relevant: 1) the total dry biomass accumulation rate in mg/day, 2) the rate of descent of roots into the soil in cm/day, and 3) the dry root: total biomass ratio, a unitless proportion which was transformed by computing arcsine $(R: T)^{1/2}$ for analysis (Zar 1984). The total dry biomass accumulation rate provided a general indication of overall plant performance in a given soil type. The depth achieved by a seedling's roots was considered important because seedlings have been found to colonize as flood waters recede (Warren and Turner 1975: Fenner et al. 1984; Stevens and Waring 1985), and root growth rate value must be sifficiently rapid to permit seedlings to maintain root contact with the subsiding water table. The dry root to total biomass ratio provided a measure of a seedling's proportional allocation of resources to roots as compared to total biomass. Data from these experiments were analyzed using SPSS analysis of variance and covariance and multiple analysis of variance and covariance and analysis of variance probrams (Hull and Nie 1981).

RESULTS OF THE STUDY

The Seed Stage

Seed Characteristics: Saltcedar seeds were found to be minute (mean dry mass = 0.014 milligrams (mg)/seed, n = 100) and readily wind dispersed (mean fall rate in still air at 25° Celcius (C) = 0.187 m/second (sec), n = 100). Saltcedar seeds produced during the summer remained viable for up to 45 days under ideal field conditions (ambient humidity and full shade) or as little as 24 days when exposed to direct insolation and desiccation. Winter field longevity under ideal conditions was approximately 130 d. Seed mortality appeared to be due to desiccation because previously viable seeds gradually shriveled in the field. Saltcedar seeds can be kept viable in the refrigerator for more than 1.5 yr. These findings indicated that the saltcedar seed reservoir in natural settings do not persist through the winter months and saltcedar seed generations in the seed reservoir did not overlap in time.

Germination Requirements: Saltcedar seeds were found to germinate equally well in light or dark and had no dormancy or after-ripening requirements. Germination was not density dependent, as demonstrated by equivalent proportion of germination across a density gradient of 10 or more than 300 seeds/dish in the laboratory. Germination required direct contact with water or extremely high humidity and is extremely rapid. At 20°C (68°F) imbibition lasted for approximately 2 hr, during which time the seed swelled to about twice its normal size. The hypocotyl began to emerge at 2 hr, and the seed became photosynthetically active within 5 to 10 hr. Germination "root hairs" emerged by hour 10 and the seed coat (with the pappus still attached) was shed between hours 10 and 20. Tap root emergence began after hour 20. Thus saltcedar germination was completed in less than one day after initiation of imbibition.

Germination Sites: The germination site survey showed that the mean distance between saltcedar seedlings and canopy plants was 2.7 + 0.55 m (8.86 + 1.8 ft; n = 97) and mean canopy diameter of mature plants was 0.45 + 0.15 m (1.48 + 0.49 ft; n = 59). Saltcedar seedlings were most common near the river and no seedlings were found above the 1,700 m^3/sec (60,000 cfs) stage, the approximate 10 year flood stage for the dam-controlled Colorado River corridor. Although saltcedar seedlings have been reported in densities of 17,000/m^2 (1,580/ft^2; Warren and Turner 1975), high density seedling beds occurred only following spring and summer flooding, and seedling beds were found only in silty substrates, not in the sand-dominated deposits which typify Grand Canyon beaches (Waring and Stevens 1987). In all cases of saltcedar germination observed in the Grand Canyon to date, germination sites had been recently disturbed by flooding or by human activities. Saltcedar seedlings which germinated beneath the canopies of mature saltcedar or other plants did not survive more than 3 months (Waring and Stevens 1987). The germination site survey also revealed that saltcedar seedlings growing in bedrock cracks along the Colorado River had germinated in minute silt/clay deposits in those cracks, and growth rates there were greatly retarded, rarely exceeding 5.0 cm/yr (2.0 in/yr); sometimes these plants appear to be permanently stunted to < 20 cm in total height over 18 yr of observation. Above- ground growth of these plants died back each year and new stems sprout each year. Complete stem die-back was also common for many plants that germinate late in the summer months on Colorado River sand bars. Such findings should be considered when saltcedar tree ring counts are used to interpret flood history (Hereford 1984). In summary, germination site requirements for saltcedar included silt or smaller particle fluvial or lacustrine substrates, which had been recently deposited or disturbed, were continuously moist (for at least one month), and were, at most, only slightly shaded.

Germination and Environmental Gradients: Saltcedar germination occurred across a wide range of pH values, from pH = 5.0 through 11.0, although germination was reduced at both extremes of this range. Maximum germination occurred between pH values of 7.0 and 9.0. Substrates beneath saltcedar canopies in the field commonly had Ph values of 6.0 to 7.0 (Waring and Stevens 1987), thus saltcedar germination success is reduced under saltcedar canopies.

Saltcedar germination success was negatively correlated with salinity, with no germination at NaCl concentrations in excess of approximately 0.75M NaCl. However, some germination of saltcedar seeds occurred at NaCl concentrations of 0.5M (34.35% salinity or 292,200 ppm). Although field salinity levels in pre-dam sediments in Grand Canyon may exceed 1,000 ppm (Waring and Stevens 1987), saltcedar germination success is probably not greatly reduced by those conditions, and the author (unpublished observations) has observed saltcedar growing from halite seeps at Colorado River km (Rkm) 96 left side looking downstream (L), and 101L.

The Seedling Stage -- Environmental Gradients

Light Intensity: Light intensity strongly influenced saltcedar seedling growth rates and survivorship. Ambient light intensity less than 20% strongly curtailed saltcedar seedling growth rates, and survivorship declinded to zero below 2.8% ambient light. Because light intensity in mature saltcedar stands is commonly less than 5% of ambient levels (Waring and Stevens 1987), survival of saltcedar seedlings in mature stands is unlikely. Reduction in light intensity, as well moisture stress, was deemed responsible for mortality of 120 saltcedar seedlings planted beneath mature saltcedar at River Km 69R in 1982 (L.E. Stevens unpublished data). Maximum stem elongation rates occurred at moderate shade level (35.5% ambient light), not under full sunlight ($p < 0.001$, df = 5,239, although light intensity was not evaluated between 35% ambient and full sunlight.

Soil Texture: Laboratory experiments conclusively demonstrated that saltcedar seedlings responded strongly to improved soil nutrient and textural status (Waring and Stevens 1987). In the investigation on the effects of dam-induced soil changes on saltcedar growth and survival in the Grand Canyon, saltcedar seedlings were grown for one month in pre-dam or post-dam soils collected from the Lees Ferry area. Pre-dam soils collected from perched river terraces consisted of silty quartz particles and were rich in base cations (particularly calcium), organic matter and phosphate (Waring and Stevens 1987). Post-dam soil from Lees Ferry consisted of coarse, nutrient depleted quartz sand. Saltcedar seedling root length and total biomass was significantly reduced in post-dam sand, as compared to pre-dam silt (Table 3.1). These results demonstrated that saltcedar seedling growth, and survivorship (L.E. Stevens unpublished data) was significantly reduced in post-dam substrates in the Grand Canyon, thereby limiting recruitment there. Saltcedar seedling dry above - ground biomass accumulation rate, stem elongation rate and number of lateral buds added/day were all significantly higher in pre-dam soil as compared to post-dam soil, while allocation to roots (expressed as root:total biomass ratio) increased nonsignificantly in the pre-dam soil. These results indicated that despite the fragility and slow growth rate of saltcedar seedlings, this species has a strongly plastic phenotype, and was therefore capable of surviving in diverse germination environments.

Nutrients: Single and multiple nutrient addition experiments showed that nutrients exert strong control over saltcedar seedling growth rates and allocation between below and above ground parts. All nutrient compounds containing nitrogen, including nitrate - nitrogen (N) + phosphate (P), N + potassium (K), as well as NPK and addition of complete nutrients increased saltcedar seedling growth significantly over controls given just distilled water. Relative allocation to roots was lowest in the complete nutrients, NPK, NP and N treatments. Most of the other treatments produced dried root:total biomass ratios in excess of 0.50, indicating some level of nutrient stress on the part of the plant. K + P accelerated growth slightly over N by increasing root biomass assumulation rate. Except for N and NaCl treatments, all single macronutrient and micronutrient additions has no effect on saltcedar seedling growth rates as compared to the distilled water treatment. NaCl at 0.1M increased saltcedar growth slightly but significantly over the distilled water treatment. Growth of saltcedar seedlings across a NaCl concentration gradient demonstrated that saltcedar achieved maximum growth effects at 0.10 M NaCl, and growth decreased on either side of that value.

Combined Moisture and Nutrient Gradients: The above results demonstrate that water and nutrient availability limit saltcedar seedling growth and probably survivorship. The effects of these two factors on saltcedar seedling growth and that of its most common competitor, *Salix exigua*, are shown in Table 3.3. *T. ramosissima* growth was greatest in the low water + low nutrient treatment because of increased root growth. Saltcedar seedlings grew fastest in low moisture conditions and were relatively intolerant of waterlogged soil conditions. Relative allocation to below ground growth (R:T) decreased as nutrient levels increased (Table 3.2). Water addition regulated biomass accumulation rate and controlled allocation patterns, while nutrient addition increased above-ground growth. Thus, water and nutrients both governed allocation (R:T) between above- and below-ground parts (univariate p values < 0.001, df = 1,51 and 2,51, respectively), while nutrient concentration regulated root elongation rate, the number of lateral buds (univariant $p = 0.001$, df = 1,51) and shoot length (univariate $p < 0.001$, df = 1,51). Interactive effects between water and nutrient concentrations were not significant (Hotelling's F-statistic $p = 0.181$, $df_{hypoth} = 10$, $df_{error} = 92$) because *T. ramosissima* seedling growth was reduced in the high water + high nutrient treatment. In contrast to *T. ramosissima, Salix exigua* seedlings showed significantly increased growth and decreased R:T values with increasing nutrient concentrations in the high water treatment. Low survivorship in the low water treatments demonstrated that coyote willow was more sensitive to desiccation than was saltcedar. Low survivorship in lower water treatments indicated that *S. exigua* was more sensitive to desiccation than was *T. ramosissima*. Thus, both species responded strongly to increased nutrient availability in post-dam soil: saltcedar was more tolerant of low water availability, but coyote willow used resources more efficiently in waterlogged soil.

Responses to Density: Saltcedar seedlings responded negatively to increased density of conspecifics in a 3-month growth experiment in the laboratory. Significant negative correlations were found for stem growth rate, total dry biomass accumulation rate, and lateral bud accumulation rate across a gradient of 1 to 20 plants grown in the laboratory in field-collected fluvial silt. No significant correlation existed between dry root : total biomass (allocation) ratio across this density gradient. With light and water availability controlled, chemical competition and/or nutrient exploitation were the likely growth retardant factors.

Mature Plant Stage

Morphology: Mature saltcedar plants in the field form spherical shrubs when growing singly, or an exiguous form when growing in dense stands. The wood is dense and brittle, and saltcedar forms a deep taproot (Merkel and Hopkins 1957; Gary 1963). Saltcedar were found to be apically dominant and also produced numerous lateral shoots, most of which perish from inadequate light intensity. Lateral shoots which survived grew more than 1.0 m/yr (3.3 ft/yr; Stevens 1985). This species readily produced adventitious roots in response to inundation (Wilkinson 1972; Waring and Stevens 1987), but Brotherson and Von Winkel's (1986) postulate that saltcedar commonly reproduced vegetatively was not observed in the field or demonstrated in laboratory studies. Few, if any, saltcedar in the Grand Canyon were clonally derived; "terracing" (sprouting of buried branches) was rarely or never successful; and growth of saltcedar buttings without root crown material was permanently retarded, as judged from more than 300 field and greenhouse plantings. This latter conclusion also was supported by Ando (1980).

Demography and Longevity: Saltcedar survivorship appears to match the typical Type III survivorship curve pattern (Deevey 1947), with low survival of most offspring and relatively high survival of longer-lived individuals. Survival of a cohort of seedlings at Rkm 275L (River Mile 171.5) was followed from germination in 1984 to 1987. Density declined from approximately 8,000 seedlings/m^2 to 100 seedlings/m^2 (743 seedlings/ft^2 to 9.4 seedlings/ft^2) in 2 years. This pattern of self-thinning and elevated seedling mortality was also noted in the laboratory density gradient experiment noted above. The correlation between size class and age is admittedly poor for saltcedar (Brotherson et al. 1984); however, the survey of saltcedar size classes in the Grand Canyon produced a survivorship relationship most similar to the Deevey Type III curve. Saltcedar is extremely fecund (see below), and it is highly unlikely that any propagules become established. The longevity of saltcedar is presently unknown, but it is suspected to exceed a century (Stevens 1985). Although the first confirmation of saltcedar in the study area date to 1938 (Clover and Jotter 1944), Mr. Spencer Johnson, a former resident of Lees Ferry, informed the author that he had planted a saltcedar at the Lonely Dell Ranch (near the mouth of the Paria River) in 1929.

Phenology: Saltcedar in northern Arizona produced two flushes of foliage, the first in April/May and a second flush during the summer rainy season in July/August, more than 2 months before the growing seasons ended (Stevens 1976b). The second foliage flush appeared to be weaker in moisture stressed individuals occupying pre-dam terraces in the Lees Ferry area, and the majority of mature plants in the Grand Canyon were chlorotic by late August.

A few saltcedar saplings flowered in their first year of growth (Warren and Turner 1975), but most individuals began to reproduce in their third year or later, depending on the amount of shading. Saltcedar was found to produce large quantities of pink, red or white flowers, each capable of producing 4 to 37 seeds (mean = 17.33 seeds/flower, sd = 6.336, n = 42). At lowest elevations (<1,000 m) in northern Arizona, blooming commenced in late April about one month after bud-break and flowering peaked from mid-May to early June (Waring and Stevens 1987). Plants at Lees Ferry which were less moisture stressed continued to bloom throughout the growing season, although at a lower intensity than the first blooming peak. In contrast, water stressed individuals growing above and some distance from the riverbank at Lees Ferry ceased reproduction following the spring blooming period. Plants at high elevations (ca. 2,100 m or 7,000 ft) reached peak blooming from July through mid-August.

Pollination: Experiments in which saltcedar racemes were bagged to prevent insect pollinators from reaching the flowers demonstrated conclusively that virtually no seed development occurred in saltcedar without insect visitation. Glass slides covered with silicone jelly and placed in mesh bags were used to determine 1) if pollen was transported by wind through the bags and 2) if wind pollination occurred (15 replicates). Saltcedar pollen was abundantly present on the glass slides, which indicated that wind-born pollen was available but anemophilous pollination does not occur to any large extent in saltcedar. Saltcedar is probably not self-compatible, as suggested by the total lack of seed set in 5 hand self-pollinated saltcedar racemes.

Reproductive Output: Saltcedar seed production was found to be extremely high and was highly variable. Mean seed production of 48 mature saltcedar plants at Lees Ferry in 1987 was 1.30×10^7, but the standard deviation (4.5049×10^7) greatly exceeded the mean. One large individual produced approximately 2.75×10^8 seeds in one season; however, 25% of the population produced few or no seeds in 1987. Further evidence of high variability in saltcedar seed production was demonstrated by the poor correlation between seed production and canopy volume ($R^2 = 0.185$, $p < 0.002$, df = 47). An additional 30 mature saltcedar plants under observation since 1984 revealed that low-fecundity individuals consistently failed to reproduce over 5 years. This puzzling lack of reproductive effort may be partially influenced by moisture stress, as the proportion of low-fecundity individuals in the population increased from 14% at the riverside to 50% on dry, pre-dam terraces at Lees Ferry ($Chi^2 = 8.00$, $p < 0.005$, df = 1); however, individuals growing in close proximity to each other varied tremendously in reproductive output.

Light, Water and Texture (Nutrient) Gradients: The response of 2 year old saltcedar saplings to 3 levels of light, 3 levels of water and 3 levels of soil texture (and nutrient availability) at Lees Ferry demonstrated that soil textural changes associated with stream regulation in the Grand Canyon did not significantly reduce mature saltcedar or *Salix exigua* growth; however, ambient light intensity and moisture availability significantly influenced the growth of these two species (Table 3.3). Saltcedar growth increased linearly with increased ambient light intensity, while coyote willow responded in a curvilinear fashion and grew somewhat slower than saltcedar. This difference produced a significant species x light interaction effect (Table 3.3). Moisture availability was also correlated with increasing growth rates for both species, except at low light levels. Allocation to roots was positively correlated with light availability for both species. Allocation to roots was only weakly positively correlated with moisture availability for saltcedar, meaning that saltcedar allocation patterns did not change in response to water. Allocation to roots was negatively correlated with moisture availability for coyote willow, meaning that coyote willow stem growth prospered in high-moisture settings and fared poorly in low moisture settings. All other higher level interaction effects were not significant. In summary, this experiment revealed that 1) light and water availability regulated these 2 species' growth patterns; 2) sexually mature saltcedar grew faster and were more drought tolerant than coyote willow, as was also demonstrated for seedlings of these two species; 3) coyote willow allocation to roots was positively correlated with moisture availability, while saltcedar allocation patterns were negatively correlated with moisture availability.

Disturbance: Saltcedar has been shown to be less susceptible to scouring removal and drowning than most native perennial riparian species (Warren and Turner 1975; Stevens and Waring 1985). Studies of flooding along the Colorado River in the Grand Canyon in 1983-1984 (Stevens and Waring 1985) revealed higher relative survivorship of saltcedar during flooding events, most probably attributed to the anchoring effect afforded by its deep tap-root (Gary 1963). Waring and Stevens (1987) also demonstrated that saltcedar seedlings are more resistant to inundation stress than were other native species.

Riparian vegetation studies in Grand Canyon revealed that saltcedar was ubiquitous in the Colorado River corridor, with a relative importance value aproaching 0.60; however, the relative importance of saltcedar in tributary canyons was much lower. Saltcedar generally declined in importance with distance upslope and away from the stream channel, except in perennial (wet) tributaries, where its importance was relatively consistent across the disturbance/moisture gradient that characterized stream channels.

Competition: To evaluate saltcedar's competitive abilities, interspecific competition interations were studied between saltcedar and coyote willow at the germination, seedling and mature plant life history stages (Stevens 1989a). Experimental germination of saltcedar and coyote willow seeds in fresh duff extracts of these two species at 20^{o}C (68^{o}F) and constant light in the laboratory demonstrated that neither species significantly reduced germination of the other or of its own seeds.

Experimental planting of field collected seedlings at a density of 60 seedlings/12 liter (L; 3 gal) pot demonstrated that within 3 months of growth, coyote willow seedlings significantly reduced the growth of saltcedar seedlings. At the end of the second year, saltcedar seedlings growing in the presence of coyote willow suffered strongly reduced growth and 15% higher mortality as compared to controls.

Competition between older age class saltcedar and coyote willow was investigated using a replacement series experimental design (Harper 1977). Two-year old plants of both species were grown for 3 years in 12 L pots with abundant water in medium soil texture (a 1:1 mixture of pre-dam and post-dam soil) at a density of 6 plants/pot. Proportion of each species was varied (e.g. saltcedar: coyote willow ratio varied from 6:0, 5:1, 3:3, 1:5 and 0:6 plants/ 12 liter pot), with ten replicates of each proportion. Results for above ground growth data for this experiment showed that coyote willow suppressed saltcedar growth only slightly, thus preemptive or consumptive competition appears to be of less significance to older age class plants of both species.

The effects of simple density on older age class saltcedar and coyote willow plants was studied across a density gradient of 1, 2 and 6 plants/12 L pot in medium textured soil for 3 years at Lees Ferry. The results of this experiment demonstrate that saltcedar responded negatively to crowding from conspecifics, while coyote willow was significantly more tolerant of crowding by conspecifics.

Saltcedar was observed to present invasion of its canopy space by potential competitors through several physical mechanisms. Massive accumulations of duff were found under saltcedar canopies. Commonly 10 to 20 cm (4 to 8 in) in depth, saltcedar duff deposits may exceed 1.5m (5.0 ft: L.E. Stevens unpublished 1987). This duff accumulation mechanically prevented seeds from reaching the soil surface and reduced light availability to those seedlings. In addition, during field and laboratory work it was observed that soils beneath saltcedar canopies were strongly hydrophobic. Percolation rates under saltcedar canopies were measured following a soaking rain in mid October, 1987 at Rkm 150 (River Mile 93.0L). After 12 hours, rain water percolated 29 cm (11.4 in) through unvegetated soil and 12 cm (4.75 in) of percolation had taken place under *Tessaria sericeae* canopies; however, only 1.0 cm (0.4 in) of percolation had taken place under saltcedar canopies (n = 9 samples/canopy type). Resins and/or sugars shed from the foliage probably serve as percolation retardants under saltcedar canopy. By water-proofing the soil surface, saltcedar strongly reduces the survival of understory seedlings of all species, including its own seedlings.

Brotherson and Von Winkel (1986) and Brotherson and Field (1987) concluded that saltcedar deposited NaCl beneath its canopy as an allelochemical agent. However, in a survey of soil characteristics beneath saltcedar canopies, Waring and Stevens (1987) found no evidence of increased NaCl beneath the canopies of 20 stands of saltcedar in the Colorado River corridor Grand Canyon.

Herbivory: While more than 250 species of herbivores were found to consume saltcedar in its Eurasian homeland, few saltcedar herbivore species occurred in the New World (Leisner 1971; Stevens 1985; Waring and Stevens 1987). Appendix 3A (Waring and Stevens 1987) lists all invertebrate herbivores reported for saltcedar in the United States. The most important invertebrate herbivore in the Grand Canyon region was the exotic saltcedar leafhopper, *Opsius stactogalus* Fieber (Cicadellidae), which occasionally reached outbreak levels on rapidly growing saltcedar and accounted for more than 90% of the invertebrate herbivore biomass on this plant species. The exotic saltcedar scale (Diaspididae: *Chionaspis etrusca* Leonardi) attacked saltcedar plants growing in drier areas in the Grand Canyon, and achieved outbreak levels in late summer and fall of up to 2,525 scales/g (1.15 x 10^6 scales/lb) dry foliage. This species appears to be expanding its range to higher elevations and upriver: it was common below 600 m (1970 ft) elevation in northern Arizona prior to 1980, appeared at River Kilometer 224 (River Mile 139) in 1984 (Waring and Stevens 1987), and was collected at Lees Ferry for the first time in 1988. Both of these herbivore species were apparently accidentally introduced from Eurasia and may have enjoyed an ecological release from their many potential competitors on saltcedar in its homeland. The saltcedar plant bug, *Parthenicus* near *ruber* Van Duzee (Miridae), is an ubiquitous, low-density and presumably native saltcedar herbivore. A flower-eating tortricid (?) moth, active from late August through October, was observed to consume 65% to more than 90% of all saltcedar flowers (L.E. Stevens unpublished 1987). The Shoshoni locust (Locustidae: *Schistocerca shoshoni* Schudder), a generalist herbivore, has been occasionally observed to completely defoliate the second flush to saltcedar foliage in mid-summer in the Grand Canyon (Stevens 1976b).

Stevens (1985) compared the invertebrate herbivore communities associated with saltcedar and coyote willow (*Salix exigua*). These two riparian plant species were found to co-occur over a broad elevational and latitudinal range in the western United States. A 50-sweeps netting technique on 3 stands of saltcedar and 3 stands of coyote willow from 1980 to 1983 in the Grand Canyon revealsed that saltcedar supported an average of 394.7 herbivores (n = 40 samples, sd = 690.39), 3.61 herbivore species (sd = 1.64), with a dry herbivore standing crop of 3.59 mg/g plant material (n = 17, sd = 4.18). The herbivore community on saltcedar was strongly dominated by *Opsius stactogalus* Fieber with an evenness of 0.35 (n = 39, sd = 0.35). Coyote willow supported equivalent numbers of invertebrate herbivores, but nearly 4 times as many herbivore species and a much lower standing crop. The herbivore community on coyote willow was much more evenly distributed, and was composed of several genera of cicadellid leaf-hoppers, geometrid moths and chrysomelid beetles.

Extreme levels of saltcedar herbivory by *Opsius* were shown by Leisner (1971) to cause deformaton and or mortality of caged saltcedar plants. To test the importance of invertebrate herbivory on saltcedar and coyote willow, two experiments were performed. One hundred saltcedar and 100 coyote willow branches were marked at a site in the Grand Canyon (Rkm 69L, River Mile 43.0L). Fifty branches of each species were sprayed at monthly intervals with Malathion™ and the other 50 branches were sprayed with river water. Stem growth of the two sets of branches were not significantly different after one full season of growth, indicating that invertebrate herbivory did not reduce growth rates of saltcedar or coyote willow (Stevens 1985).

In another experiment, 0%, 25%, 50%, 75% and 100% of the leaf area was removed from 10 plants of saltcedar and coyote willow at three localities in the Grand Canyon. Growth following defoliation was monitored for one year. Defoliation or more than 75% resulted in significantly reduced growth the following year, fo required to reduce growth the following year ($F = 9.067$, $p < 0.001$, $df = 4, 50$). While natural defoliation of coyote willow, with its many herbivore species, may exceed 40% per yr in the field, defoliation of saltcedar was considerably less. Thus except in relatively rate cases of nearly complete defoliation, invertebrate herbivores did not seriously limit the growth of saltcedar or of coyote willow.

Invertebrate herbivore loads appeared to be regulated by desiccation stress and therefore elevation, seasonality and regional weather patterns. Studies at low elevations in southern Arizona described the saltcedar invertebrate herbivore load as depauperate (e.g. Cohan et al. 1978), while studies conducted 300 to 1,000 m (1,000 to 3,000 ft) higher in northern Arizona found invertebrate herbivore standing crop to be equal to that on native plant species (Stevens 1985).

Vertebrate herbivores in the Grand Canyon region included (in order of importance): beaver (*Castor canadensis*), red-naped sapsucker (*Sphyrapicus nuchalis*) and, at Lees Ferry and along upper Lake Mead, black-tailed jackrabbit (*Lepus californicus*). Beaver commonly removed lateral saltcedar stems 2 - 5 cm (1 - 2 in) in diameter, even when other food plants are available, and occasionally felled large saltcedar trees (up to 30 cm -- 12 in -- in basal diameter), particularly during the autumn months.

In addition to herbivores, Brown (1987) reported at least 18 bird species nesting in saltcedar in the Grand Canyon, including several obligate riparian, Neotropical migrant species. This finding was in contrast to that of Cohan et al (1978) who found few species of birds (mostly doves) nesting in saltcedar in the lower Colorado River.

DISCUSSION

The success of exotic saltcedar in southwestern riparian habitats is attributable to its reproductive and stress tolerance-related life history traits, and to habitat availability. Saltcedar was found to be an entomophilous species with remarkable seed production capabilities (up to 2.75 x 10^8 seeds/year per plant) and depends virtually solely on wind and water dispersal of its seeds. Saltcedar has not demonstrated self-compatability, and out-crossing is expected for species that face unpredictable germination and growing conditions. Germination sites for saltcedar varied considerably, ranging from fine sediment to cracks in streamside bedrock to mudflats at the headwaters of reservoirs, from below sea level in Death Valley to more than 2,000 m elevation, and in salinities ranging from near 0 ppm to those exceeding 50,000 ppm. Fine fluvial or lacustrine substrates provided the optimal germination sites, and saltcedar seedling densities in those settings reached 17,000 seedlings/m^2 (1,580 seedlings/ft^2; Warren and Turner 1975). In all cases observed, saltcedar germination occurred in disturbed settings, such as along the margins of flood-prone waterways or at the heads of reservoirs following subsidence of floodwaters. Saltcedar seeds were minute and longevity was dependent on the ambient temperature regime; however, there was no overlap in seed generations between years. Saltcedar seeds had no dormancy requirements and germinated in approximately 20 hours. Saltcedar seedlings were intolerant of shade and grew rather slowly as compared to other woody riparian perennials. Mortality related to disturbance was age-dependent in saltcedar seedlings (Waring and Stevens 1987). Consequently, saltcedar recruitment occurred after significant disturbance (flooding) events and saltcedar stands tended to be even-aged in the Grand Canyon (Hayden unpublished: Brotherson et al. 1984).

Saltcedar was more tolerant of environmental stress than were other woody riparian perennials in the Southwest. Waring and Stevens (1987) concluded that saltcedar was resistant to dessication, inundation and burial, but not to exposure of its root crown. Seedling and mature saltcedar were repeatedly found in the present study to be more tolerant of dessication than were coyote willow and several other native riparian species. *T. ramosissima* seedlings were shown to be more tolerant of inundation stress (Waring and Stevens 1987) and desiccation stress than its most common competitor, *Salix exigua*, although the latter species used resources more efficiently in waterlogged soil. Mature saltcedar in the field were capable of withstanding inundation for 3 months in anoxic reservoir waters and more than 2.5 years in cold, well-oxygenated lotic settings (Warren and Turner 1975; Waring and Stevens 1987). With its well-anchored tap-root (Gary 1963) and excellent tolerance of moisture-related and other (e.g. burial) stresses, saltcedar suffered relatively low mortality from flooding as compared to native riparian species in the Grand Canyon in 1983-84 (Stevens and Waring 1985).

Brotherson and Field's (1987) claim that saltcedar is a chemically aggressive, competitive species was not supported by experiments conducted here. Although saltcedar did occupy saline soils, there was no evidence that saltcedar increased salinity at the ground surface. Saltcedar strongly reduced germination site quality under its own canopy by 1) depositing vast quantities of duff (a pre-emptive competitive strategy) and 2) by shedding resins or sugars on the soil surface which render the soil hydrophobic. Saltcedar seedling growth rate was regulated by density dependent (chemical or nutrient depletion) mechanisms, and self-thinning was rapid in seedling beds. Seedling saltcedar were competitively inferior to seedling coyote willow (a chemical or nutrient-based interaction). Chemical and consumptive competition between mature plants was not shown to be significant. Because coyote willow seedlings are rare in this system, the effects of chemical or nutrient consumptive competition (c.f., Schoener 1983) were unlikely to regulate saltcedar populations in the Grand Canyon. In summary, saltcedar was capable of preempting space from native riparian species through mechanical means but its success was not attributable to chemical or nutrient competition.

The controversy regarding the ecological value of saltcedar in riparian habitats was apparently linked to an elevational/desiccation stress gradient, with low elevation (< 305 m or 1,000 ft) saltcedar populations depauperate and desiccation stressed, and higher elevation populations supporting a greater abundance and diversity of invertebrate herbivores, herpetofaunae and avifaunae. The invertebrate herbivore and vertebrate component communities associated with saltcedar at low elevations have been described as depauperate (Cohan et al. 1978; Johnson 1986), while saltcedar in the Grand Canyon was found to support a large populations of herbivorous invertebraes and provided significant habitat for many of the riparian herpetofauna and avianfauna (Stevens 1976a, b, 1985; Waring and Stevens 1987; Brown et al. 1984; Brown 1987; Warren and Schwalbe 1987). Furthermore, an elevation gradient within the Grand Canyon appears to be positively correlated with the abundance and biomass of phloem feeding invertebrates (Stevens 1985), while desiccation stress appears to be negatively correlated with herbivore abundance and biomass. Therefore, desiccation stress at low elevations may prevent invertebrate herbivory, and plant moisture stress in this species may regulate insectivorous vertebrate community dynamics.

Greater invertebrate herbivore loads at higher elevation sites have probably not significantly limited the growth or dispersal or saltcedar because more than 75% of the foliage had to be removed to reduce saltcedar growth significantly in the following year. Differential invertevbrate herbivore loads were approximately equivalent on saltcedar and coyote willow in the Grand Canyon; however, coyote willow had a slight selective advantage because it was dispersed by beaver and floods in that system.

Riparian succession in the Southwest is the result of differential survival and growth (Campbell and Green 1968; Turner and Karpiscak 1980; Stevens and Waring 1985) in spatially and temporally rare safe germination sites following seasonal but sporatic, flood-induced germination events, and the seedling phase is typically the most sensitive life history stage (Silvertown 1982; Fenner et al. 1984; Kozlowski 1984; Waring and Stevens 1987). Abiotic ecological factors, such as flooding, are considered to regulate riparian plant community dynamics and succession (Campbell and Green 1968; Campbell and Dick-Peddie 1968; Kozlowski 1984), inundation and/or desiccation stress (Waring and Stevens 1987), and pedogenesis, while important biotic factors may include predation (herbivory and disease) and competition. Riparian succession can only proceed between major disturbance (flooding) events because flooding disturbance "resets" or reverses natural, pedogenic processes in riparian habitats. Flooding reduces the abundance, distribution, and species richness of mature plants, while simultaneously exposing new patches of the habitat and thereby increasing germination site availability. For example, Stevens and Waring (1985) reported strongly differential mortality between riparian plant species and significantly reduced plant diversity, coupled with a major germination event, following record post-dam flooding of the Colorado River corridor in 1983-84.

The Colorado River corridor vegetation in the Grand Canyon has been undergoing riparian succession. Populations of native riparian plants have increased in relation to saltcedar populations in the post-dam era (Martin unpublished 1971; Turner and Karpiscak 1980; Brian 1982; Waring and Stevens 1987; Phillips et al. 1987). While it is unclear if saltcedar invasion has continued at its initial, rapid rate (Robinson 1958; Crhistensen 1962; Graf 1977), the pattern of riparian succession observed in the Grand Canyon has apparently not occurred in geomorphologically similar, but largely unregulated, reaches of the upper Colorado River basin, such as Cataract Canyon. Abiotic, dam-induced ecological changes (e.g., disturbance regime and soil quality changes) appear most important in driving this successional pattern; however, biotic ecological mechanisms (pre-emptive competition and herbivory) may be temporally or spatially important.

From this discussion it can be seen that the success of saltcedar in southwestern riparian habitats has been due to: its fecundity; its germination requirements and behavior; its tolerance of water-related stresses and fire; its propensity for pre-emptive exclusion of potential competitors; and not to its "aggressive", chemical/consumptive competitive abilities nor to ecological release from herbivory. The distribution and success of this species were found to be intimately linked to disturbance, both natural and anthropogenic (e.g., stream regulation), which provided an abundance of suitable germination sites in the arid, eroding landscapes of the Southwest. Saltcedar dispersal and recruitment was intimately dependent on flooding disturbance, and reduction of flooding disturbance in the Colorado River corridor in the Grand Canyon reduced recruitment success of saltcedar. This point was demonstrated by the prevalence of saltcedar in primary, rather than seocondary, successional settings. Overall, saltcedar was found to be better adapted to the wide range of unpredictable environmental conditions found in disturbed riparian habitats than were most native riparian species. For the most part, saltcedar invaded an "empty niche" (*sensu* Price 1984) in southwestern riparian systems, and did not replace a pre-existing flora.

Riparian habitats, including wetlands, are the most productive, most valuable and most threatened habitats in the American Southwest (Johnson et al. 1985). The processes affecting succession and stability of riparian habitats therefore deserve far more attention than they have received. Saltcedar is an abundant component of the southwestern riparian flora and its natural history and ecological role are likewise important to our understanding of proper management of riparian ecosystems.

Table 3.1: Seedling growth characteristics for 30 day old saltcedar seedlings grown in the laboratory in pre-dam versus post-dam soil from Lees Ferry, Arizona.

GROWTH RATE PARAMETER	Signif.[h]	PRE-DAM SOIL MEAN (N, SD)	POST-DAM SOIL MEAN (N, SD)
Root Biomass (mg/d)[d]	NSD	0.100 (12,0.0593)	0.130 (10,0.1387)
Stem Biomass (mg/d)[d]	*	0.099 (12,0.0698)	0.037 (10,0.0362)
Total Biomass (mg/d)[d]	Not Calc'd	0.199 (12,0.1161)	0.167 (10,0.1718)
Root:Total Biomass	NSD	0.507 (12,0.1437)	0.763 (10,0.1244)
Root Length (cm/d)	NSD	0.410 (12,0.1290)	0.370 (10,0.1243)
Stem Length (cm/d)	**	0.125 (12,0.0392)	0.067 (10,0.0445)
Number of Lateral Buds Added/day	*	0.145 (12,0.0756)	0.062 (10,0.0882)

d -- dried biomass
h -- Hotelling's multivariate F statistic=5.3077, p=0.005, df=6,14
(NSD = no statistical difference; * $p < 0.05$; ** $p < 0.01$; df for univariate tests = 1,19)

Table 3.2: Multiple analysis of variance table for root:total biomass ratios for 30 day old *Tamarix ramosissima* seedlings grown in coarse, post-dam sand under 2 levels of water and 3 levels of nutrients.

SOURCE	**HOTELLING'S APPROXIMATE F**	**HYPOTH DF**	**ERROR DF**	**p VALUE**
Water	13.0122	5.00	48.00	0.000
Nutrients	17.2345	10.00	94.00	0.000
Water x Nutrients	1.4266	10.00	94.00	0.181
Constant	1146.223	5.00	48.00	0.000

Table 3.3: Multiple analysis of variance (MANOVA) table of a 4-way nursery experiment with 2 year old cuttings of 2 species (*T. ramosissima* and *Salix exigua*) grown for one year under 3 levels of light, 3 levels of water and 3 soil textures.

SOURCE	**HOTELLING'S F**	**HYPOTH DF**	**ERROR DF**	**SIGNIFICANCE OF**	**F**
Species (Sp)	8.2267	5.00	135.00	0.000	
Light (L)	18.0589	10.00	268.00	0.000	
Water (W)	2.3439	10.00	268.00	0.012	
Soil (S)	0.9733	10.00	268.00	0.467	NSD
Sp x L	4.9432	10.00	268.00	0.000	
Sp x W	0.9855	10.00	268.00	0.456	NSD
Sp x S	0.9205	10.00	268.00	0.515	NSD
L x W	1.8149	20.00	534.00	0.017	
L x S	1.1132	20.00	534.00	0.331	NSD
W x S	0.9627	20.00	534.00	0.507	NSD
Sp x L x W	1.3096	20.00	534.00	0.166	NSD
Sp x L x S	1.3584	20.00	534.00	0.137	NSD
Sp x W x S	0.6871	20.00	534.00	0.841	NSD
L x W x S	1.2179	40.00	667.00	0.169	NSD
Sp x L x W x S	1.0169	40.00	667.00	0.444	NSD
Constant	367.213	5.00	135.00	0.000	

Administrative Issues Surrounding the Management of Saltcedar

INTRODUCTION

The Colorado River is highly regulated and is primarily managed for water storage, hydroelectric power and environmental concerns by the Bureau of Reclamation, with land management by the National Park Service. The Colorado River flows 450 km between Glen Canyon Dam and upper Lake Mead through lower Glen Canyon (25 km) and all of Grand Canyon.

Since the early 1980s, the US Bureau of Reclamation (BOR) oversaw intensive scientific studies conducted by its staff, the US Geological Survey, US National Park Service, US Fish and Wildlife Service, and the Arizona Fish and Game Department to document spatial and temporal changes in the Colorado River ecosystem. Based on an Environmental Impact Statement completed in 1995 (GCD-EIS; BOR 1995) and a Record of Decision (1996), the managing agencies adopted an "Adaptive Management Program" to seek best strategies for balancing potentially conflicting goals of water use, recreation, and protection of native species (Schaefer 1997). Diurnal low flows prevented development of benthic communities over much of the upper river bottom, and severely limited reproductive success of at least rainbow trout (exposing redds to drying, forcing juveniles to move into areas of high predation risk). Aquatic productivity, or at least the area of shallow river bottom that can support algal and benthic insect community development, has responded dramatically to reduced diurnal variation under the interim flows (IF) and moderate low fluctuating flows (MLFF) dam management policies. The IF and MLFF flow policies have apparently reduced the transport of sand from the main channel to higher elevation eddy deposits, resulting in net erosion of camping beaches prized by white water rafters. High flows, such as the 1996 experimental flood, were recognized as necessary to deposit sand at higher stage elevations and rebuild sand bars (BOR 1995). These management activities affect both terrestrial habitats, food resources and occasionally populations of species of concern.

Much of the concern regarding saltcedar control stems from the elevated invertebrate herbiovore production and preferential use by Neotropical migrant songbirds of saltcedar for nesting and foraging habitat. This exemplified by the altered habitat use patterns of southwestern willow flycatcher (Tyrannidae: *Empidonax trailli extimus),* as described below, as well as that of other bird species, and numerous herpetofaunal and mammal taxa.

INVERTEBRATE USE OF SALTCEDAR

More than 250 species of herbivores were found to consume saltcedar in its Eurasian homelandl however, only a few native and non-native saltcedar herbivorous invertebrates occur on saltcedar in the New World (Leisner 1971; Stevens 1985; Waring and Stevens 1987). Appendix 3A (Waring and Stevens 1987) lists all invertebrate herbivores reported for saltcedar in the United States. The most abundant invertebrate herbivore in the Grand Canyon region is the exotic saltcedar leafhopper, *Opsius stactogalus* Fieber (Cicadellidae), which occasionally reached outbreak levels on rapidly growing saltcedar and accounted for more than 90% of the invertebrate herbivore biomass on this plant species. This species plays an important role in the diets of riparian avifauna, including Lucy's Warbler (Johson et al. 1997), as well as lizard species. The exotic saltcedar scale (Diaspididae: *Chionaspis etrusca* Leonardi) attacked saltcedar plants growing in drier areas in the Grand Canyon, and achieved outbreak levels in late summer and fall of up to 2,525 scales/g (1.15 x 10^6 scales/lb) dry foliage. This species appears to be expanding its range to higher elevations and upriver: it was common below 600 m (1970 ft) elevation in northern Arizona prior to 1980; it was first collected at Rkm 224L (River Mile 139) in 1984 (Waring and Stevens 1987); and it was not detected during intensive invertebrate sampling efforts in 1974-1976 and 1980-1984 at Lees Ferry, was collected there for the first time in 1988, and is now abundant there. Both of these herbivore species were apparently accidentally introduced from Eurasia and may have enjoyed an ecological release from their many potential competitors on saltcedar in its homeland.

Native invertebrate herbivores on saltcedar include several species. Two species of saltcedar plant bug, *Parthenicus* nr. *ruber* Van Duzee (Miridae), are ubiquitous and occur in modest densities. A flower-eating noctuid moth, *Characoma nilotica* (Rogenhofer), is active from late August through October, was observed to consume ≥90% of all autumn saltcedar flowers (L.E. Stevens unpublished 1987). The Shoshone locust (Locustidae: *Schistocerca alutacea shoshone* Scudder), a generalist herbivore, has been occasionally observed to completely defoliate the second flush to saltcedar foliage in mid-summer in Grand Canyon (Stevens 1976b).

SOUTHWESTERN WILLOW FLYCATCHER

Distribution and Abundance

The southwestern willow flycatcher (SWWF; *Empidonax trailii extimus*) is a Neotropical migrant subspecies. Overall, the willow flycatcher species has a broad breeding range, extending from Nova Scotia to British Columbia and south to Baja California. The SWWF is an obligate riparian insectivore (Hunter et al., 1987), preferring habitat near open water (Gorski 1969; Sogge 1995). The historic breeding range of the SWWF includes Arizona, New Mexico, southern California, and southern portions of Nevada, Utah, and perhaps southwestern Colorado, and extends east into western Texas (U.S. Fish and Wildlife Service 1993). It probably winters from Mexico to Panama, with historical accounts from Colombia (Phillips 1948). The SWWF is distinguished from other subspecies by distribution, morphology and color, nesting ecology, but not by song dialect (Phillips 1948, Aldrich 1953, King 1955, Sogge 1995).

The southwestern regional SWWF population has declined over the past 50 years, corresponding with loss and modification of riparian habitats, as first noted by Phillips (1948). Southwestern riparian ecosystems support a rich avian fauna (Johnson and Haight 1987) and habitat changes have resulted in reduction or extirpation of many avian species (Hunter et al., 1987). Modification and fragmentation of these systems through development and livestock grazing have precipitated devastating changes to SWWF populations. Destruction of native willow/cottonwood vegetation has provided opportunity for invasion by non-native plant species, notably saltcedar. Habitat fragmentation and modification has been beneficial to some southwestern avian species, especially cowbirds (*Molothrus* spp.), which parasitize SWWF nests, contributing to the precipitous population declines of SWWF (Brown 1994, Johnson and Sogge 1995, Sogge et al. 1995). SWWF habitat loss in Central and South America has also undoubtedly contributed to recent SWWF population declines, although little information is available.
The SWWF has been extirpated from much of its range (Hunter et al. 1987). Population reduction since 1950 was so dramatic that it was proposed (U.S. Fish and Wildlife Service 1992) and listed, with critical habitat, under the Endangered Species Act, on July 23, 1993 (U.S. Fish and Wildlife Service 1993). The SWWF is more rare than most other currently listed avian species (Unitt 1987). An estimated 300-500 breeding pairs remain in the United States, including 115 pairs in California and approximately 100 pairs in New Mexico (U.S. Fish and Wildlife Service 1993). Limited information exists for Colorado, Utah, Nevada, and Texas. It has been

given special protection status by the Game and Fish Departments in Arizona, New Mexico and California.

Arizona has experienced the sharpest decline in SWWF numbers. SWWF formerly bred throughout the state at high and low elevations (Paradzick et al. 1999). For example, a 1931 breeding record exists from the south rim of the Grand Canyon (Brown et al., 1984), indicating that this taxon bred at high elevations, even at the northern edge of its range. By 1987, the State population was estimated at less than 25 pairs (Unitt 1987; U.S. Fish and Wildlife Service 1993), but much habitat was not surveyed. At least 52 territories or active nests were reported during extensive surveys in 1993 in Arizona (Muiznieks et al. 1994), and at least 62 active nests were located during a more thorough inventory in 1994 (Sferra et al. 1995). In Arizona, there were approximately 113 SWWF pairs in 1996 (Sferra et al. 1997), and in 1998 250 nesting attempts were detected in 34 drainages, with 53.0% nest success.

From 1974 through 1996 the Grand Canyon population was detected between Colorado River miles 47 and 71 (Unitt 1987, Sogge et al. 1995, 1997). In its recent proposal the Service included the Colorado River from River Mile 39 to River Mile 71.5 as critical habitat U.S. Fish and Wildlife Service 1993), and stipulated in a subsequent final rule that defines such habitat as that "within 100 meters of the edge of areas with surface water during the May to September breeding season and within 100 meters of areas where such surface water no longer exists owing to habitat degradation but may be recovered with habitat rehabilitation" (U.S. Fish and Wildlife Service 1997) . The boundary of this area in Grand Canyon includes the main Colorado River channel and associated side channels, backwaters, pools and marshes.

SWWF were common in Glen Canyon and the lower San Juan River prior to impoundment by Glen Canyon Dam (Woodbury and Russell 1945, Behle and Higgins 1959). This area was inundated by Lake Powell and no singing male SWWF were detected from 1991-1998 in the Glen Canyon reach below the dam, however, a singing individual was detected in 1999 (Brown 1991a; J. Spence, Glen Canyon National Recreation Area, Page, Arizona, personal communication). SWWF were rather commonly reported along the pre-dam Colorado River at Lees Ferry, with records at Lees Ferry in 1909, 1933, 1935, and 1961, and near Lava Canyon in 1931 and near the Little Colorado River confluence in 1953 (reviewed by Sogge et al. 1997); however, the pre-dam distribution of SWWF in Marble Canyon and through Grand Canyon is poorly known. Carothers and Sharber (1976) reported only one pair of SWWF in Grand Canyon in the early 1970's surveys. Brown (1988) noted a brief population increase in the Grand Canyon from two in 1982, to a maximum of 11 (two in Cardenas Marsh), with a subsequent decline to seven in 1987. Brown (1991a) detected two pairs in 1991, with nests located at River Mile 50.7 and at River Mile 71.1 (Cardenas Marsh). Surveys in 1992 detected seven SWWF, three unpaired males and two breeding pairs in Cardenas Marsh (Sogge et al. 1995a). A total of five SWWF were detected in Grand Canyon in 1995: three territorial but non-breeding males and one breeding pair that fledged a single young (Sogge et al. 1995a). The unpaired male SWWF established territories between Colorado River miles 50.5 and 65.3, and the breeding pair nested at mile 50.5. In 1996 Sogge et al (1997) reported three singing SWWF, but only one successfully breeding pair along the Colorado River in upper Grand Canyon. The single pair apparently fledged two young. In 1997, the single nest in upper Grand Canyon was parasitized by brown-headed cowbirds. A single SWWF nest near mile 265 in 1997 produced two young (Grand Canyon Monitoring and Research Center 1997). After 1996, SWWF failed to nest successfully in upper Grand Canyon because of cowbird brood parasitism (M. Sogge, U.S. Geological Survey Biological Resources Division, Northern Arizona University, Flagstaff, AZ, personal communication). The single nesting pair of SWWF at Mile 50.5L in upper Grand Canyon has failed to produce young successfully since 1996 (J. Spence, op. cit., personal communication). A pair established a territory at that site in 1999, but nesting failed again. Other 1996-1998 reports of SWWF breeding in the lower Colorado River basin have stimulated additional research there.

The U. S. Fish and Wildlife Service's 1996 Biological Opinion on a planned flood in Grand Canyon in 1996 defined several measures to mitigate impacts on the SWWF in Grand Canyon. Stevens et al. (1996) studied habitat changes at four historic SWWF nest sites in Grand Canyon. Fluvial marshes associated with these sites were dominated by common reed, horsetail and cattail. SWWF research activities associated with that flood included verifying stage-to-discharge relations, quantifying flow depth and velocity at nest sites, and determining nest site and foraging habitat structure, litter/understory characteristics, and nesting success.

The 1996 Experimental Flood impacts on Grand Canyon SWWF habitat were reported by Stevens et al. (1996 and in press). Nest stand vegetation impacts were nominal: two stands were slightly scoured, and three sites sustained a slight reduction in ground cover and/or branch abundance at <0.6 m above the ground; however, no reduction in branch abundance or alteration of stand composition occurred, and the flood did not inundate the bases of any historic nest trees. Impacts on marsh foraging habitats were more severe, with decreases in area of 1% to >72%. Two of four SWWF sites regained vegetated area during the summer of 1996, while two other marshes sustained slight additional losses in cover through the 1996 growing season. The 50.05L marsh has not recovered appreciably since the 1996 flood (L.E. Stevens, unpublished data).

Life Requisites

SWWF arrive in the Grand Canyon area in mid-May, but may be confused with another subspecies, the more common *E. t. brewsteri*, which migrates through to more northern breeding grounds (Aldrich 1951; Unitt 1987). E.t. brewsteri sings during migration, making sub-specific distinctions difficult until mid-June (Brown 1991b). Males arrive earlier than females and establish territories. The characteristic territorial song is a "fitz-bew," most frequently heard in the morning before 10 AM (Tibbitts et al., 1994), and both male and female birds produce this call (H. Yard, Flagstaff, AZ, unpublished data).

SWWF are highly territorial. Nest building begins in May after breeding territories are established. The nest is placed in a fork or horizontal branch 1-5 meters above ground (Tibbetts et al. 1994). A clutch of three or four eggs is laid from late May through July (Unitt 1987), but in Grand Canyon two or three eggs (usually three) are usually laid (Sogge 1995). Breeding extends through July and singing ceases at the end of the breeding season.

After a 12-14 day incubation, nestlings spend 12 or 13 days in the nest before fledging (Brown 1988; Tibbetts et al., 1994). The breeding season (eggs or young in nest) in Grand Canyon extends from early June to mid-July, but may extend into August. One clutch is typical, however re-nesting has been known to occur if the initial nest is destroyed or parasitized (Brown 1988).

Riparian modification, destruction and fragmentation provided new foraging habitat for brown-headed cowbirds (*Molothrus ater*) and populations of brown-headed cowbirds continue to expand (Hanka 1985, Harris 1991). Brood parasitism is currently the greatest threat to SWWF and probably many other Neotropical migrants as well (Bohning-Gaese et al., 1993; Sogge et al., 1995). Over half the nests in Brown's study (1988) contained brown-headed cowbird eggs. Cowbirds may remove prey eggs, their eggs hatch earlier, and the larger nestlings are more competitive in the nest. Cowbirds fledged from Sierra Nevada SWWF nests while SWWF nestlings died shortly after hatching (Flett and Sanders 1987). Brown-headed cowbirds occur extensively around mule corrals on the rim of the canyon and travel down to the Colorado River.

SWWF may remove cowbird eggs or, more commonly, abandon the nest if the parasite's eggs are deposited. The second nesting attempt is energetically expensive, requiring a new nest to be built (Sogge 1995), although Brown (1988) noted that a SWWF pair covered a cowbird egg with fresh nesting material and laid a new clutch. The second nest, already at a temporal disadvantage, is often parasitized as well. Cowbird parasitism could be largely responsible for the absence of SWWF in otherwise suitable habitat in the Grand Canyon (Unitt 1987). Bronzed cowbirds (Molothrus aenus) have recently been reported colonizing the Grand Canyon and represent another threat (Sogge 1995).

The SWWF in Grand Canyon occupy sites with average vegetation canopy height and density (Brown and Trossett 1989). SWWF commonly breed and forage in dense, often multistoried, riparian vegetation near surface water or moist soil (Whitmore 1977, Sferra et al., 1995), along low gradient streams (Sogge 1995). Nesting in Grand Canyon typically occurs in non-native saltcedar 4-7 m tall, with a dense volume of foliage 0-4 m from the ground (Tibbetts et al., 1994). SWWF commonly and preferentially nest in saltcedar in upper Grand Canyon (Brown 1988), and nested in saltcedar in Glen Canyon before completion of the Glen Canyon Dam (Behle and Higgins 1959). Arizona SWWF preferentialy nest in saltcedar: 194 of 203 nests detected in 1998 were situated in Tamarix (Paradzick et al. 1999). Although habitat is not limiting in Grand Canyon (Brown and Trossett 1989), required patch size is not known. The 1997 and 1998 nesting records from lower Grand Canyon demonstrates that this species can colonize new habitat (e.g., the delta of Lake Mead).

Stevens and Waring (1988) demonstrated that saltcedar is exceptionally tolerant of flooding in the Grand Canyon, persisting through many weeks of inundation. The saltcedar trees in which the SWWF presently nest survived the >92,600 cfs flows of 1983 as well as the 1996 flood (Stevens et al. 1996), and are therefore unlikely to be scoured by future small floods.

Proximity to water is necessary and is correlated with food supplies. Little is known of SWWF food preferences but it is probably a generalist feeder. They typically flycatch (sally) from conspicuous perches, but also hover and glean insects from foliage (L.E. Stevens, personal observation). SWWF also forage on sandbars, backwaters, and at the waters edge in the Grand Canyon (Tibbetts et al., 1994).

SWWF return to wintering grounds in August and September (Brown 1991b), but neither migration routes nor wintering areas are well known. Birds sing and perhaps defend foraging territories in Central America during winter, and winter movement may be tied to water availability (Gorski 1969). Threats to SWWF on the wintering grounds are poorly documented, but habitat losses in Latin America may be a major factor in the decline of this species.

Impacts of Habitat Modification on SWWF

Although little is known of SWWF food preferences, it is probably a generalist feeder on invertebrates. It typically hovers and gleans insects from foliage, or flycatches from conspicuous perches (L.E. Stevens, personal observation). SWWF also forage on sandbars, backwaters, and at the water's edge in the Grand Canyon (Tibbetts et al., 1994). SWWFs likely forage on both adult aquatic flying invertebrates, and terrestrial (non-aquatic) flying invertebrates. Although aquatic species are unlikely to be affected by the loss of some saltcedar cover, populations of terrestrial invertebrates, such as *Opsius stactogalus* leafhoppers, are likely to be strongly affected, and without planting of alternative host plant species, food resources for SWWF and other Neotropical migrant species are likely to be substantially reduced by largescale saltcedar control.

SALTCEDAR USE BY OTHER RIPARIAN VERTEBRATES

Saltcedar stands provide food and habitat resources for numerous riparian herpetofauna in Grand Canyon. Species showing an elevated affinity for saltcedar include: *Bufo* toads, desert spiny lizard, western whiptail lizard, striped whipsnake, and the endemic Grand Canyon rattlesnake (L.E. Stevens, personal observation).

In addition to SWWF, many Grand Canyon Neotropical migrant bird species use or nest preferentially in saltcedar. Brown et al. (1987) reported at least 18 bird species nesting in saltcedar in the Grand Canyon, including several obligate riparian, Neotropical migrant species. This list includes hummingbirds, blue grosbeak, lazuli bunting, Lucy’s warbler, yellow warbler, yellow-breasted chat, Bell’s vireo, indigo bunting, and wintering sapsuckers (Brown and Trossett 1989; Johnson et al. 1997). This finding was in contrast to that of Cohan et al (1978) who found few species of birds (mostly doves) nesting in saltcedar in the lower Colorado River.

Mammals actively using saltcedar in the Grand Canyon region included (in order of importance): beaver (*Castor canadensis*), deer mice (*Peromyscus eremicus* and *P. maniculatus*), woodrats (*Neotoma* spp.), and, at Lees Ferry and along upper Lake Mead, black-tailed jackrabbit (*Lepus californicus*), in the Lake Mead area. Beaver commonly removed lateral saltcedar stems 2 - 5 cm (1 - 2 in) in diameter, even when other food plants are available, and occasionally felled large saltcedar trees (up to 30 cm -- 12 in -- in basal diameter), particularly during the autumn months.

History, Methods and Success of Saltcedar Control

Saltcedar has a rather deeply (approximately 1 m) deep root crown, from which it resprouts after damage or loss of above ground growth. This architectural feature greatly protects the plant from mortality by above ground disturbances, and makes control problematic. Control of saltcedar has been widely assessed, and many methods have been attempted, including cutting, fire, electrocution, hot wax treatment, biological control, mechanical removal, and herbicide treatment (Kunzman et al. 1989). The latter two techniques have proven most effective, and were used in Grand Canyon for this project.

Grand Canyon Wildlands Council and the National Park Service at Grand Canyon National Park set back saltcedar invasion in 63 tributaries of the Colorado River, killing saltcedar by uprooting smaller plants and cutting and immediately applying Garlon® to the freshly cut stems of larger plants. We used teams of well-trained staff and were able to treat about one tributary/day. By removing saltcedar from Grand Canyon tributaries, we expect to have set back the invasion process there by 50 yr or more.

This tamarisk control methodology has been used successfully in numerous situations throughout the Southwest, including: The Nature Conservancy’s Hassayampa Preserve, near Wickenburg, Arizona; Thousand Palms Canyon in California’s Mohave Desert, Zion Canyon in Zion National Park, numerous springs in Death Valley National Park, at Grand Wash springs in Lake Mead National Recreation Area. These programs uniformly report good or complete success. These efforts shared several common reasons for their success. The first was good administrative support for the tamarisk control efforts. The application of Garlon must be within the first three minutes of cutting the stem (see Kunzman et al. 1989), and October-November was considered the best time period for control success, as tamarisk is resorbing leaf products at that time at low elevations. Although control efforts required several years of volunteer labor in cases with heavy infestation of large sites (e.g., Thousand Palms, California), only modest maintenance was typically required to keep tamarisk from re-invading the treated sites. None of these efforts reported any environmental problems were encountered with the use of Garlon.

In accord with the National Environmental Policy Act (NEPA), the National Park Service completed an Environmental Assessment (EA) for the saltcedar control program in Grand Canyon. After the EA was finalized, the protocols for saltcedar control were presented. Initially, there was debate over whether and how to control saltcedar, whether by cutting and direct application of Garlon, use and dosage of Garlon with the "EZJect" capsule applicator, manual removal, or a combination of these control methods. For the control methods used, Grand Canyon Wildlands Council and the National Park Service collaboratively monitored the results by revisiting the sites, recensusing transects on which the densities of native and non-native plant species, including saltcedar, were monitored prior to treatment, and evaluating the success of the control efforts. NEPA compliance and the experience gained by conducting both the tributary control efforts and the pilot native plant revegetation efforts at Lees Ferry (described below) will be used to evaluate the specific future goals for saltcedar control in Glen and Grand canyons.

Grand Canyon Wildlands/National Park Service at Glen Canyon National Recreation Area also collaboratively engaged in a program to replace a 4 ha saltcedar stand downstream from the launch ramp at Lees Ferry, Arizona with native Fremont cottonwood, Goodding willow and other native shrub species. This site was photographed in pre-dam time, and prior to the arrival of saltcedar in the 1920's-1930's, this site was dominated by native riparian plant species. Grand Canyon Wildlands and the NPS mechanically removed saltcedar, and planted a beaver-protected stand of native trees and shrubs, monitoring plant growth over the subsequent three years and changes in the bird community. This effort was overseen by Fred Phillips (Fred Phillips Consulting), who has successfully transformed more than 2 km of the lower Colorado River shoreline near Parker, Arizona into native cottonwood and willow stands (Phillips 1998). As of 1 April 2001, stand removal was completed, water lines were being installed, and planting was scheduled for May 2001. Maintenance of this site was conducted by Flagstaff Native Plant and Seed, Flagstaff, Arizona, and overseen by Fred Phillips Consulting and Grand Canyon Wildlands Council. Success at this site has large implications for non-native plant control and revegetation management in Glen and Grand canyons.

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APPENDIX 3A:

PHYTOPHAGOUS INVERTEBRATES COLLECTED FROM

TAMARIX RAMOSISSIMA DENEB. IN THE UNITED STATES

REFERENCES: 1. Bibby (1942); 2. Glinski and Ohmart (1984); 3. Hopkins and Carruth (1954); 4. Hefley (1937); 5. Liesner (Unpub'd. 1971); 6. Stevens (1985); 7.Watts et al. (1977); 8. Waring and Stevens (1987); 9. Stevens and Waring (1988).

ORDER / **Family**	**Reference**
ACARINA	
Tetranychidae	
Tetranychus bimaculatus Harvey	5,7
Acarina sp.	6
ORTHOPTERA	
Gryllidae	
Gryllid sp.	6
Oecanthus quadripunctatus Beutenmuller	4
Locustidae	
Aeolopus arixonensis Scudder	3
Hesperotettix viridis (Thomas)	8
Melanoplus differentialis (Thomas)	3,5,7
Melanoplus occidentalis (Thomas)	5,7
Schistocerca lineata Scudder	5,7
Schistocerca shoshoni Scudder	3,6
Schistocerca vaga (Scudder)	3
Trepidulus rosaceus Scudder	7
Phasmidae	
Diapheromera arizonensis (Caudell)	3
Diapheromera covilleae Rhen & Hebard	7
HOMOPTERA	
Aphididae	
Aphis craccivora Koch	5,7
Aphis gossypii Glover	5,7
Aphis medicaginis Koch	3
Macrosiphum pisi (Harvey)	3

Macrosiphum solanifolii (Ashm.)	3
Myzus persicae (Sulzer)	3
Aphidid spp. I-IX	6,8
Cercopidae	
Clastoptera ovata Doering	7
Cicadellidae	
Aceratagallia sanguinolenta (Provancher)	5,7
Aceratagallia uhleri (Van Duzee)	5,7
Aceratagallia sp.	5,6,7
Amblysellus gres (Oman)	6
Balclutha neglecta (DeLong & Davidson)	7
Carneocephala sp.	5,7
Ceratagallia neodona Oman	5,7
Chlorotettix viridis Van Duzee	4
Colladonus belli (Uhler)	5,7
Cuerna stiata (Walker)	7
Coleranus lucidus (Baker)	7
Empoasca abrupta DeLong	3
Empoasca sp.	5,6,7
Homolodisca liturata Ball	3
Idiocerus apache Ball & Parker	7
Idiocerus alternatus Fitch	5,7
Idiocerus nervatus Van Duzee	5,7
Idiocerus rufus Gillette & Baker	5,7
Idiocerus snowi Gillette & Baker	5,7
Idiocerus sp. I	6
Keonolla dolobrata (Ball)	7
Keonolla uhleri (Ball)	5,7
Lonatura salsura Ball	5,7
Macropis viridis (Fitch)	7
Macrosteles fascifrons (Stal)	7
Opsius stactogalus Fieber	3,5,6,7
Xerophloea viridis (Fabricius)	5,7
Cicadellid spp. I-V	6
Cicadidae	
Tibicen (Diceroprocta) cinctifera (Uhler)	5,7
Tibicen (Diceroprocta) apache	2,6,8,9
Tibicen inauditus Davis	5,7
Tibicen townsendi (Uhler)	5,7
Okanagana utahensis	8
Cixiidae	
Oeclus campestris Ball	7

Oeclus cucullus Kramer	8
Oeclus decens Stal	3,7
Oecleus venosus Van Duzee	5,7
Oliarus sonoitus Ball	5,7
Oliarus sp.	5
Coccidae	
Pulvinaria innumerabilis Rathon	5,7
Coccid spp. I-II	6
Delphacidae	
Delphacodes sp.	5,7
Diaspididae	
Chionaspis etrusca Leonardi	3,5,6,8
Flatidae	
Mistharnophantia sima Doering & Shepard	5,7
Ormenis saucia Van Duzee	5,7
Ormenis yumana Ball	3
Membracidae	
Cyrtolobus sp.	7
Leioscyta ferruginipennis (Goding)	5,7
Multareis cornutus lawsoni Cook	5,7
Publilia modesta (Uhler)	5,7
Pseudococcidae	
Phenacoccus helianthi (Cockerell)	5,7,8
Puto sp.	7
Psyllidae	
Heteropsylla texana Crawford	5,7
Kuwayama medicaginis Crawford	5,7
Paratrioza cockerelli (Sulc.)	3
Psylla near *alba* Crawford	5,7
Trioza collaris Crawford	5,7
Psyllis spp. I-II	6
Aleyrodidae	
Near *Trialeurodes*	8

HEMIPTERA

Berytidae

Berytid sp.	6
Cydnidae	
Cydnoides albipennis (Say)	7
Coreidae	
Near *Leptoglossus*	6
Mozena sp.	3
Lygaeidae	
Liorhyssus hyalinus Fabricius	1
Neacoryphus lateralis (Dallas)	7
Hysius raphanus Howard	1,5,6,7
Hyonysius californicus (Stal)	5,7
Lygaeid spp. I-II	6
Miridae	
Lopidea sp.	7
Lygus hesperus Knight	1,5,7
Lygus lineolaris (P. uB.)	3
Lygus pratensis Linnaeus	4
Melanotrichus coagulatus (Uhler)	5,7
Orthotylus sp.	5,7
Parthenicus near *ruber* Van Duzee	6,8
Parthenicus sp. II	8
Phytocoris sp.	5,7,8
Polymerus basalis (Reuter)	5,7
Slaterocoris stygicus (Say)	5,7
Mirid spp. I-III	6
Pentatomidae	
Brochymena parva Ruckes	8
Brochymena sulcata Van Duzee	3
Chlorochroa ligata (Say)	3
Chlorochroa sayi Stal	3,7
Pentatomid sp.	6
Pyrrhocoridae	
Euryopthalmus convirus Stal	3
Rhopalidae	
Aufeius impressicollis Stal	7
Liorphyssus hyalinus Fabricius	5,7,8
Stictopleurus viridicatus (Uhler)	7

COLEOPTERA

Anthicidae	
Anthicus cervinus La Ferte	7
Anthicus sp.	5,7
Notoxus caudatus Fall	7
Notoxus calcaratus Horn	7
Anthicid sp. I	8
Bostrichidae	
Amphicerus cornutus (Pallus)	5,7
Amphicerus simplex (Horn)	5,7
Bruchidae	
Acanthoscelides chiricahuae (Fall)	7
Acanthoscelides collusus (Fall)	7
Acanthoscelides compressicornis (Schaeffer)	7
Acanthoscelides fraterculus (Horn)	8
Acanthoscelides prosopoides (Schaeffer)	7
*Algarobious prosopi**s*** (LeConte)	7
Mimosestes amicus (Horn)	7
Mimosestes protractus (Horn)	7
Buprestidae	
Buprestis confluenta Say	7
Chrysobothris strofasciata LeConte	3
Hippomelas sp.	6
Psiloptera drummondi Castelnau	5,7
Chrysomelidae	
Altica near *torquata* LeConte	8
Altica near *foliacea* Le Conte	7
Chaeatocnema ectypa Horn	3
Chaeatocnema sp.	7
Colaspoides sp.	7
Coscinoptera near *dominicana* Fabricius	5,7
Coscinoptera tricincta (Say)	7
Diachus auratus (Fab.)	8
Pachybrachis arizonensis Bowditch	5,7
Pachybrachis croftus Bowditch	7
Pachybrachis hepaticus Melsheimer	4
Pachybrachis near *nigurm* Melsheimer	7
Pachybrachis mitis Fall	7
Pachybrachis sexnotata Bowditch	4
Pachybrachis signatus Bowditch	5,7
Pachybrachis sp.	6
Phyllotreta sp.	7

Trirhabda canadensis (Kirby)	7
Chrysomelid spp. I-VIII	6,8
Cleridae	
Cymatodera oblita Horn	7
Enoclerus coccineus (Schenckling)	7
Enoclerus cordifer (LeConte)	7
Enoclerus quadrisignatus (Say)	7
Monophylla californica (Fall)	7
Phyllobaenus sp. I	5,7
Phyllobaenus sp. II and III	7
Trichodes bibalteatus LeConte	7
Near *Trichodes*	7
Cryptophagidae	
Cryptophagus prob. *croceus* Zimmerman	8
Cucujidae	
Ahasverus near *advena* (Waltl.)	5,7
Oryzaephilus surinamensis (Linnaeus)	5,7
Curculionidae	
Apion sp.	5
Epimechus sp.	8
Hypera punctata (Fabricius)	7
Ophryastes sp.	7
Pandeleteinus sp.	7
Sitona hispidula (Fabricius)	7
Smicronyx near *interruptus* Blatchley	7
Smicronyx near *lutulentus* Dietz	7
Dermestidae	
Cryptohopalum festivum Casey	7
Cryptohopalum fontinal Casey	7
Trogoderma stenale Jayne	7
Elateridae	
Dicrepidius corvinus Candeze	7
Histeridae	
Hololepta populnea LeConte	7
Lyctidae	
Trogozylon aequale (Wollaston)	5,7
Melyridae	

Amercocerus near *annulatus* Casey	6
Attalus spp. I-III	7
Hypebaeus sp. I	8
Trichochrous sp.	7
Vecturoides pseudonychus Fall	8
Mordellidae	
Diclidia sp. I and II	7
Mordella brevistylis Lijeblad	7
Mordellistena sp.	7
Pentaria trifasciata (Melsheimer)	7
Phalacridae	
Phalacrus sp.	7
Rhipiceridae	
Sandalus californicus Lac.	3
Tenebrionidae	
Tribolium castaneum (Herbst)	7
Scarabaeidae	
Ochsosidia arizonica Casey	3
CORRODENTIA	
Undetermined	3
PSOCOPTERA	
Lachisillidae	
Lachesilla sp.	5,7
Psocoptera sp.	6
LEPIDOPTERA	
Sphingidae	
Hyles lineata	9
Arctiidae	
Estigmene acraea Drury	3
Geometridae	
Geometrid sp.	6
Lyonetiidae	

Bucculatrix sp.	7
Noctuidae	
Characoma nilotica (Rogenhofer)	8
Tarachidia sp.	7
Psychidae	
Oiketicus townsendi Cockerell	7
Thyridopteryx ephemeraeformis Haworth	4
Pyralidae	
Crambus sp.	7
Scythridae	
Scythris sp.	7
THYSANOPTERA	
Thripidae	
Franklinella occidentalis (Pergande)	3,5,6,7
Thripid sp.	6
HYMENOPTERA (Parasitic)	
Dryinidae	
Gonatopus sp.	5,6?,7
Mymaridae	
Barypolynema saga Girault	5,6,7

SECTION 4: REVEGETATION, MONITORING, AND PHOTO MONITORING PLANS

4a: Revegetation, Monitoring, and Photo Monitoring Plan for Lees Ferry

By Fred Phillips

REVEGETATION PLAN

Clearing

The grantee shall clear all tamarisk and exotic plant vegetation, and prepare the site for revegetation in a selective manner, saving any valuable native trees and shrubs already on the site. The contractor will coordinate all clearing activities with the GCNRA maintenance crew and rangers. The sites in sections 1 and 2 will be used by boaters for camping. These are only temporary camping sites and are subject to review as part of river planning. The grantee shall clear and kill tamarisk by the following method:

1. Selective Clearing with a D-6 bulldozer and leaving the cleared material in windrows on site. The cleared material left on site will also act as habitat and cover for small mammals and invertebrates.

Tillage

The grantee shall auger holes (approximately 1000) with a backhoe or similar equipment at least 18 inches in diameter and 8' deep (or to the water table, if shallower) where each propagule is to be planted. The existing tilled soil will serve as the planting medium in each augured hole.

Irrigation System

The grantee shall construct an irrigation system for the ten acres of revegetation. The irrigation system will consist of a 2-3" polyethylene main (depending on available water pressure) line running along the length of the north border of the site with 1/2" polyethylene laterals running south from the main line. Each planting hole (approximately 1000) will have 1-6-gallon per hour drip emitters attached to the ½" inch laterals. The grantee shall install the irrigation system above ground. The system will run from the 6" existing water main running along the north border of the site. 2- 2" pressure-compensating valves with backflow and filter and an electric irrigation timer installed at the bathroom facility will be the control devices for the irrigation system. All construction activities will be coordinated with the GCNRA and GCNP maintenance crew and rangers during the construction period.

Propagules

The grantee shall take cuttings of local genetic stock and plant the propagules in one-gallon pots. Potting material will consist of equal portions of sandy soil from the revegetation area, and composted mulch. The propagules will consist of the following plants in the following amounts. The extra plantings (300) will be used to replace dead or dying trees in the revegetation project:

Propagule Name	Approximate amount
Goodding’s willow (*Salix gooddingii*),	120
Coyote willow (*Salix exigua*),	170
Fremont cottonwood (*Populus fremontii*),	400
Fourwing saltbush (*Atriplex canescens*),	150
Seepwillow (*Baccharis salicifolia*),	150
Inkweed (*Suaeda torreyana*),	150
Netleaf Hackberry (*Celtis reticulata*),	20
Desert Olive (*Forestiera neomexicana*),	20
Greasewood (*Sarcobatus vermiculatus*).	20
Apache Plume (*Falugia paradoxa*)	20
Shrub live oak (*Quercus turbinella*), Liners not 1 gal	20
Squawbush (*Rhus trilobata*)	20
Single Leaf ash (*Fraxinus anomola*)	20
Box Elder (*Acer negundo*)	20
Total # of propagules	**1300**

The propagules will be prepared from cuttings (when possible) and seeds from existing local genetic stock. The grantee shall prepare approximately 1300 propagules for the site. This number will provide approximately 300 extra plants for dead plant replacement. The propagules will have an established root system and be in healthy growing condition at planting. The Fremont cottonwood and the sandbar and Goodings willow will have a minimum height of 18-24” when they are planted. A final planting list with exact numbers for each species needed will be submitted to the grantee upon the final planting design in December 2000, the final planting list will not drastically change from the preliminary list and the total propagules number and species used will not change. From the preliminary site investigations a majority of the plant species used will be Goodings willow, sandbar willow, Fremont cottonwood, fourwing saltbush, inkweed and seepwillow.

Planting

In the first week in May (or one and a half months into the growing season) the grantee shall plant the aforementioned plant species according to the final planting design. The grantee will place 2 slow release fertilizer tablets in each planting hole. At each planting the grantee shall install 3’ high, 18” diameter ring of 2” grid hog wire secured to 2-3/4” rebar posts. Areas where the individual hog wire rings are not installed the contractor will install a 3 foot high hog wire beaver fence with ¾” rebar posts on 10’ centers as specified in the final planting design to control browsing by beaver and damage to the young trees. The fence will be buried at least two inches into the existing soil to prevent beavers and small rodents from establishing runs under the fence.

Irrigation and Weeding

The grantee shall ensure that approximately 8 gallons of water per day is delivered to each tree through six gallon per hour pressure compensating emitters for 7 days a week for 20 weeks or until the end of the first growing season. The grantee will be responsible for weekly maintenance of the irrigation system to ensure that timers and valves are operating correctly. The grantee will also clear and/or replace any clogged/dysfunctional emitters during this weekly maintenance. The grantee shall weed exotic and invasive plants and replant dead trees as needed during the first season irrigation period. Before the second growing season the grantee will replace and repair any damaged sections of the irrigation system and starting at the onset of the growing season irrigate the site at a rate of 8 gallons per planting/day, 7 days a week for the first month of the growing season (April or May). The grantee will also replant dead trees with any leftover plant stock from the original 1300 propagules. The grantee will also weed the site from exotic plant species during this month of irrigation. By this point in the second growing season the plantings should be well established for long-term self-sustainability. If it is determined that additional irrigation is required the contractor will continue irrigation maintenance into the second growing season until plants are well established. The grantee (GCWC) is responsible for all of the work described in this scope of work and the long-term maintenance of the project (20 Years) until an o&m agreement is executed. GCNRA will only be responsible for the maintenance of this project once an o&m agreement is made (prior to June 2002)) this agreement process is currently underway.

VEGETATION MONITORING

The primary objective of this project is to establish 10-acres of long-term self-sustaining native cottonwood and willow riparian habitat in the 100-year floodplain at Lees Ferry. Additionally, the grantee will determine whether or not exotic species will regenerate, and if so, to what extent, once removed from the site where native species are established. After tamarisk is removed from the revegetation site, native species Freemont cottonwood *(populus fremontii*), goodings willow (*salix gooddingii*), sandbar willow (*salix exidua*), and four-wing saltbush (*atriplex canescens*) will be planted according to resulting suitability determinations outlined in the revegetation plan. As native species regenerate, the threat of non-native invasive species decreases considerably and a direct correlation is noted between the return of native plant species and increase in native avifauna.

Monitoring objectives

The grantee shall determine how characteristics such as soil type, electrical conductivity (EC), and depth to the water table affect the survivability and successful establishment of cottonwood, goodings willow, sandbar willow, and four-wing saltbush. Thus, monitoring will involve the following:

A. Observation of plant species-specific percent survival and growth rates.
B. Determination of species survivability based on variations in depth to the water table and salinity (EC) levels.
C. Calculation of foliage volume and density.
D. Determine the viability of this revegetation method for establishing long-term self-sustainable riparian habitat.

Strategies

The grantee will measure the success of the objectives by observing how data collected falls into success-rating categories.

A. The Grantee will observe success criteria specific to each species. This will be measured as follows:

Species	5-year goal % survival	height (in)	10-year goal % survival	height (in)
Fremont cottonwood	80-100%	200-300”	60-90%	240-360”
Gooddings willow	80-100%	200-265”	60-75%	220-300”
Sandbar willow	75-80%	135-265”	60-80%	140-280”
Four-wing saltbush	60-80%	24-60”	50-80%	24-72”

B. Site features that may influence data collections are insect damage, browsing, soil erosion and drift, and edge effects such as vandalism resulting from proximity to the boat launch at the site. Insect damage, browsing, and edge effects will be noted as monitoring takes place.

C. Baseline site conditions have already been established through vegetation analysis of plant species type and density conducted by the Grand Canyon Monitoring and Research Center. (Larry Stevens will also be conducting pre and post bird species density and richness).

D. The grantee will be able to conclude if the objectives are being achieved by evaluating all data collected, specifically by measuring where the survival and growth rates fall within the success criteria in conjunction with observations on the overall health of each species, degree of foliage volume and density, whether or not the tree suffered insect damage or browsing, lack or degree of weed encroachment and evidence of native plant regeneration. Additionally the grantee can compare baseline conditions with those at various intervals throughout the monitoring process.

Data Collection Methods and Sampling Plan; Quantitative Monitoring:

1) Soil samples will be taken from the surface and at a depth of 1.5 meters at each corner and the center of the site, for a total of 10 samples. These results, as well as existing soil data previously collected by the Grand Canyon Monitoring and Research Center, will be used to calibrate an EM38 meter. The EM38 meter, which is capable of taking one sample per second, will then be used to gather EC levels at the surface and at 1.5 meters at each planting hole throughout the site. From the data collected, salinity levels and soil type will be mapped. A planting design will be developed from this information. Sample transects consisting of cottonwood, willow, and saltbush will be assigned to randomly selected planting holes throughout the 10-acre site and monitored for growth and survival. Monitoring will involve examining the established sample set for browsing and insect damage, and measuring tree height from the base of the trunk to the top of the tallest up-stretched leaf. Ground cover and foliage volume will also be calculated using the resulting measurement.

2) Equipment needed to collect data is minimal; the grantee will need a tape measure that will extend from the base of the trees’ trunk to the tip of the tallest up-stretched leaf. As the trees’ growth surpasses the tape measure’s capabilities, a PVC pole with measured interval markings, or similar device, will be used to obtain data.

3) Sampling sites will be randomly selected by using a computer to generate four random numbers within each acre of the 10-acre site. These numbers will correspond a planting hole; that hole along with the three consecutive holes will comprise the sample set of each of the four plant species.

4) Intensive sampling involves samples from approximately 10% of the population. In order to gather a more accurate picture of salinity effects on this 10-acre site and to allow for future in-depth statistical analysis of the data, we opted to sample 16% of the trees planted. This allows for 40 transects, four in each of the 10 acres, providing an equal distribution of samples throughout the area. Each sample will consist of one of each of the four plant species, all in the same order: cottonwood, gooddings willow, sandbar willow, and four-wing saltbush. Thus, there will be 160 individual samples total; 40 of each species, four of each species in every acre.

5) Data collection by the grantee will involve bi-weekly monitoring throughout the first growing season, and monthly monitoring during the second growing season. Additional monitoring will take place annually in December of each consecutive year.

6.) Data collected from monitoring outlined in section 4. A. 1). will be statistically analyzed using a 95% confidence interval level and a comparison will be drawn from actual data the established success criteria outlined in section 3.

PHOTOGRAPHIC MONITORING

The Grantee will establish four photo-monitoring points on the 10-acre site; two points at high locations and two at low locations, adjacent to the river. Vital to the scientific validity of this monitoring is information such as a detailed description of the photo point, as well as established position coordinates, photographer, date, time, weather, and camera height.

4b: Pre and Post Revegetation Avian Monitoring Plan for Lees Ferry Revegetation Project

By Larry Stevens

INTRODUCTION

Pre-treatment and post-treatment avian monitoring will be used to help determine the extent of beneficial effect of the tamarisk control project on bird populations in the Lees Ferry area. A monitoring program will be conducted on the 10 acre revegetation project site and a nearby untreated site along the Colorado River 0.1 mi downstream from the mouth of the Paria River. The latter site will serve as a control, and pre- versus post-treatment data from the Lees Ferry site will be used to further document the impacts of the project. Additionally, maintaining an already established control site affords a potential opportunity for long term monitoring beyond the scope of this grant.

METHODS

The avian monitoring plan will consist of establishing a transect of known length (approximately 200 m) on each of the two sites and collecting avian census data on the sites prior to and after the treatment period. The transect will be the full length of the treated area and the control site, and will pass longitudinally through the sites. Recent aerial photographs will be obtained from the Bureau of Reclamation and used to develop a site map for the two sites. Oblique photographs will be taken at fixed points on each site during each season, and according to the standards established by AWPF.

Avian census data collection will consist of a modified Emlen approach, with at least a 30 minute walk along the transect, with regular one-two minute stops to detect all birds on the site, along the periphery, and flying overhead. The site visits will be conducted in the morning hours where possible. These data will represent an estimate of the total avifauna and bird abundance at each site during each visit. Data will be recorded in a field book, and will include the time of day, weather conditions (temperature, wind speed, cloud cover, precipitation, etc.), the location on the transect, the identity and number of all birds detected, and any other pertinent observations. A total of 10 site visits will be made in the first six months following contract execution on both study sites. A total of 32 visits will be made on each site in 2001-2002 (typically 3/month during the April-June breeding season, and 2/month thereafter).

Data will be compiled in an Excel spreadsheet and presented to Grand Canyon Wildlands and AWPF in progress reports and the final report. Data will be prepared for publication in a peer-reviewed scientific journal.

Pre-Revegetation Avian Censusing at Lees Ferry

The consultant will compile historical data from the Grand Canyon Monitoring and Research Center, L. Stevens personal data archives over the past decade, and Glen Canyon National Recreation Area data collected by J. Spence over the past five years. This will be presented in an Excel spreadsheet. Census data from the untreated control site will be compared with five years of data collected and recorded by Grand Canyon Monitoring and Research Center (J. Spence, personal communication). These data will be considered as baseline, pre-revegetation data.

Analysis for this task will consist of a paired comparison of control and treated plot data. We will use avian abundance/hr of observation and species detected/hr of observation data in a nonparametric paired-test statistic, such as the Wilcoxon signed rank test. This will demonstrate whether consistent differences exist between the control site and the treated site. These results will be compiled into a component report, and presented to the GCWC for inclusion in the progress and final reports to the AWPF. Results will be prepared for peer-reviewed scientific publication.

Post-Revegetation Avian Census

The grantee will conduct 30 post-restoration censuses in the revegetated area, beginning in March 2001 and continuing through December 2003. Censuses will be conducted 3/month in April, May and June, monthly in July-October, and bimonthly thereafter, for a total of 16/yr. Additional censuses (16/yr) will be conducted on the control transect.

The consultant will compare pre-treatment with post-treatment effects at the treated site, using a Mann-Whitney test and a graphical analysis of avian abundance detected/hr of observation and species detected/hr of observation over the growing season. A similar analysis will be conducted on the data collected from the control site. These results will be compiled into a component report, and presented to the GCWC for inclusion in the progress and final reports to the AWPF.

RESULTS

Reporting and data formatting will follow AWPF guidelines, as listed in the “AWPF Reporting and Data Format Guidelines.”

4c: Tamarisk Eradication, Monitoring, and Photomonitoring Plan for the Colorado River

By Lori Makarick

OBJECTIVES AND SIGNIFICANCE

The primary objective of this portion of the overall project is to remove tamarisk from 63 tributaries of the Colorado River in Grand Canyon National Park. This will provide two main benefits: 1. It will significantly reduce the tamarisk within the treated areas. 2. It will allow native vegetation to reestablish itself in the absense of exotic plants. Another project objective is to monitor the success of the tamarisk removal through pre- and post-removal plant monitoring. The eradication and the monitoring design and implementation are discussed in this plan.

Tributaries of the Colorado River are among the most pristine watersheds and riparian habitat remaining in the coterminous United States. These riparian systems deserve a high level of protection from non-native plant invasion. The recent encroachment of tamarisk into these tributaries poses a significant threat to the integrity of the natural ecosystems. Grand Canyon National Park is committed to the preservation of native plant communities and native ecosystems. NPS management policies require park managers "to maintain all the components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (USDI 2001). Park managers are directed to give high priority to the control and management of exotic species that can be easily managed and have substantial impacts on the Park's resources (NPS 1985, USDI 2001). The removal of tamarisk from these tributaries will provide this protection, and allow native plant communities to recover. An increase of native plant species in these areas is expected once the tamarisk trees are removed.

PROJECT METHODOLOGY

Due to the remoteness of the terrain, it is necessary to access the majority of the tributaries by boat. A total of 6 river trips will be conducted over the 3-year duration of this project. Each river trip will consist of 12-16 people (including boatmen) and will be 18-days long. The trip length should allow sufficient time to access and work in the selected canyons. The teams will remove tamarisk from approximately 15 tributaries per trip totaling 63 canyons. The number of people necessary to complete eradication efforts in each area will be based on the data collected in the initial surveys. It is anticipated that the minimum number of people that will be needed for tamarisk removal in each tributary is six. The people will be carefully selected and will possess all of the necessary skills and abilities for the project implementation. Monitoring transects and photopoints will be installed on the first trip in October 2000, and two 4-person teams will be responsible for transect installation. Each 4-person team consists of two people with knowledge of Grand Canyon flora as the group leaders, and two additional active team members and assistants. Please refer to the monitoring plan below for the overall design and implementation scheme.

TAMARISK ERADICATION METHODS

The eradication methodology was finalized after all public comments were incorporated into the Environmental Assessment/Assessment of Effect (EA/AEF) document, which is required under the National Environmental Policy Act (NEPA) and the National Historic Preservation Act (NHPA). An EA/AEF is an in-depth study of the impacts of and alternative to proposed actions, and serves as a method to involve the interested and affected public before any decisions affecting the environment is made. A copy of the EA/AEF has already been provided to the AWPF. For this project, a combination of methods will be used including mechanical, chemical, cultural (i.e. seeding), and other relatively new control methods. The methods selected for each project location will be site specific and will be determined by the restoration biologist or project leader, i.e. adaptive. The following Integrated Pest Management methods will be used for this project:

Manual Removal

Seedlings in washes, streambeds, and non-sensitive areas will be manually removed. In addition to hand pulling, leverage devices (weed wrenches™) will be used for slightly larger seedlings and saplings to ensure that the entire root system is removed. Hand tools, including picks, pulaskis, and shovels may be used to loosen the soil surrounding the larger plants and then the entire root system will be removed.

Garlon Lance Injection

The lance injector has proven highly effective in controlling woody plant species in Hawaii. The lance is a three- to four-foot long tool with four chambers. Small herbicide capsules (approximately ¾" long by ¼" in diameter) are placed inside the chambers, the lance is placed against the trunk of the tree, and as the top of the lance is pushed, the chamber opens and a capsule is inserted into the tree. The number of capsules inserted into the tree is based on the trunk's diameter. The overall effectiveness of this method on tamarisk has not been determined, but is a method the park will use if proven effective. Direct herbicide injection into the tree would eliminate the possibility of chemical spillage. It would also be safer for the applicators since there is less likelihood of herbicide contact. This method would be used on large saplings and mature trees. Since the lance must be held at 45 degrees to the trunk, it will be difficult to use as the sole method in dense stands.

Hack and Squirt

With this method, a hatchet or tree girdler (similar to a small saw) is used to cut downward into the water-conducting tissue (phloem) of standing trees. The herbicide mixture is then directly applied into the cut with a hand-pressurized sprayer (and fine spray nozzle) or 12cc syringe. On larger trees, two or more cuts would be necessary. The cuts will be made at about one to two meters above the ground. This method will be used in areas with scattered individual mature trees; it will be difficult to use as the sole method in dense stands.

Cut Stump

Tree trunks are cut near ground level with handsaws and then stumps are sprayed with Garlon mixed with a penetrating agent (oil) or water. The mixture is absorbed by the plant's phloem and transported to the root; if the herbicide mixture is applied quickly (2-10 minutes), 90-95% control is possible. Pressurized hand or backpack sprayers allow precision herbicide application with minimum overspray or drift risk. This method will be used on a limited number of larger trees in dense stands and for smaller trees where manual removal would cause extensive soil disturbance.

Basal Bark Application

The entire stem is treated with Garlon from near ground level up for about 30-38 centimeters. The chemical is applied with a backpack sprayer or hand held pressurized sprayer, both of which have small nozzles with coarse spray settings that allow for direct spraying with minimal drift or overspray. A paintbrush may also be used for small sapling application. This method is much less labor intensive, but is less effective on mature trees and will be used for smaller saplings and some seedlings. It is effective on trees up to one year and three meters tall.

PROJECT TIMELINE

October 2000 – 18-day river trip, transect installation and monitoring
October 2002 – 18-day river trip, eradication trip #1
November 2002 – 18-day river trip, eradication trip #2
October 2003 – 18-day river trip, eradication trip #3
November 2003 – 18-day river trip, eradication trip #4, and post-project monitoring and follow-up maintenance
May 2004 – 18-day river trip, post-project monitoring and follow-up maintenance

INITIAL SURVEY DATA

Grand Canyon National Park completed initial, pre-project surveys for most of the 63 tributaries. The goal of the surveys was to provide initial estimates of the number of people and time necessary to eradicate the tamarisk trees in each of the areas. The numbers are valid only for the point in time the data was collected. Actual numbers of trees removed from each area will be collected during the eradication efforts. The following table contains the initial data that the park collected:

Table 4C.1: Tributary survey information.

Arizona Water Protection Fund

Tributary Survey Information

Grand Canyon National Park

Tamarisk Size Breakdown

River Mile	River Side	Canyon	Seedling	Sapling	Mature	TOTAL TARA	SW Willow Flycatcher Habitat Assessment Complete	Archaeological Resources Within 300m
11	R	Soap Creek	2000	62	10	2072	X	X
20.5	R	North Canyon	2	7	16	25	X	
37.7	L	Tatahatso Wash	0	7	1	8	X	
39	R	First redbud alcove	19	8	8	35	X	
39.2	R	Second redbud alcove	0	0	6	6	X	
40.9	R	Buckfarm Canyon	5	5	14	24	X	
41.2	R	Bert's Canyon	0	0	8	8	X	X
56.2	R	Kwagunt Creek	8	35	5	48	X	X
57.5	R	Malgosa Canyon	0	0	80	80	X	X

64.7	R	Carbon Creek	47	49	54	150	X	
65.5	R	Lava Canyon	46	245	161	452	X	X
65.7	L	Palisades Creek	0	4	11	15	○	X
69.8	R	Basalt Canyon	1000	200	40	1240	X	X
74.1	R	74 mile Wash	0	4	0	4	X	
75	R	Escalante Creek	8	19	3	30	X	
75.6	L	75 mile Creek	697	65	14	776	X	X
81	R	Vishnu Creek	10000	71	44	10115	X	
84	L	Lonetree Canyon	130	8	21	159	X	
84	R	Clear Creek	2	4	14	20	X	
85	R	85 mile Spring	5	16	5	26	X	
88	R	Lower Bright Angel Creek	1000	131	135	1266	○	
91.6	R	Trinity Creek	30	101	38	169	○	
92.5	L	Salt Creek	0	0	4	4	X	
93.5	L	Monument Creek	87	74	245	406	X	X
94	R	94 mile Creek	155	202	238	595	X	
94.9	L	Hermit Creek	230	58	25	313	X	
96.7	L	Boucher Creek	40	100	40	180	X	
99	R	Tuna Creek	487	39	70	596	X	
105	L	Ruby Canyon	6	26	36	68	X	
106	L	Serpentine Canyon	0	10	38	48	X	
107.8	R	Hotauta Canyon	11	20	20	51	X	X
107.8	L	South Bass Canyon	3	19	20	42	○	X
111	R	Hakatai Canyon	0	0	100	100	○	
112	R	Waltenberg Canyon	12	20	11	43	X	
114.5	L	Garnet Canyon	10	118	25	153	X	
116.5	L	Elves Chasm	1	10	26	37	X	X
117	L	Bighorn Wash	100	47	14	161	X	
120	R	Lower Blacktail Canyon	40	0	4	44	X	X
120	R	Upper Blacktail Canyon	0	15	16	31	X	
122	R	122 Mile Creek	2	2	10	14	X	X
122.7	L	Forster Canyon	16	83	22	121	X	X
124.9	L	Fossil Canyon	4	10	25	39	X	X
128	R	128 Mile Creek	73	37	110	220	X	
129	L	Specter Chasm	14	35	1	50	X	
130.5	R	Bedrock Canyon	96	200	94	390	X	X
131.8	R	Galloway Canyon	10	34	118	162	X	X
132	R	Stone Creek	0	2	2	4	○	
133	R	133 Mile Creek	4	17	22	43	X	
138.5	R	Cranberry Canyon	9	24	3	36	X	
139	R	Fishtail Canyon	0	1	7	8	X	X
142	R	142 Mile Spring	0	12	2	14	X	
147.8	L	148 Springs	0	0	2	2	X	
147.9	L	Matkatamiba Canyon	500	0	4	504	X	
150	R	150 Mile Canyon	15	14	1	30	X	

152	R	Spring above 152 "Ledges Camp"	19	22	15	56	X	X
155	R	Slimey Tick Canyon	158	9	4	171	X	
155.5	R	Last Chance Canyon	32	14	2	48	X	
164.5	R	Tuckup Canyon	0	3	11	14	X	
168	R	Fern Glen Canyon	0	3	1	4	X	
171	R	Stairway Canyon	3	4	4	11	X	X
174	R	Cove Canyon - Lower	14	47	74	135	X	X
174	R	Cove Canyon - Upper	350	4	7	361	X	X
209	R	209 Mile Canyon	350	102	43	495	X	X
212	R	Bessies Camp Creek	0	0	15	15	X	
214	R	214 Mile Creek	6	22	14	42	X	X

⭘ Southwest willow flycatcher habitat surveys will be completed in these areas before tamarisk control begins.

PRE AND POST TAMARISK ERADICATION MONITORING AND PHOTO MONITORING PLAN

1.) *Describe the objective of the project – brief declarative statement of biologic, hydrologic or physical changes that will result from your project.*

The primary objective of this portion of the overall project is to remove tamarisk from 63 tributaries of the Colorado River in Grand National Park. This will provide two main benefits: 1. It will decrease the colonization and spread of tamarisk. 2. It will allow native vegetation to reestablish itself without exotic plant competition. Another project objective is to monitor the success of the tamarisk removal through pre- and post-removal plant monitoring. This will help determine whether the project is successful. The overall monitoring design will tell us: 1. How successful removing tamarisk from side canyons is in reducing colonization of tamarisk. 2. How much and to what extent the native plant communities in side canyons recover and benefit from this removal.

These tributaries of the Colorado River are among the most pristine watersheds and riparian habitat remaining in the coterminous United States. These riparian systems deserve a high level of protection from non-native plant invasion. The removal of tamarisk from these tributaries will provide this protection, and allow native plant communities to recover. An increase of native plant species in these areas is expected once the tamarisk trees are removed. Tamarisk trees sequester a large amount of water through their extensive root system, and we expect to observe changes in the hydrology in some of the spring and stream areas. Additional water will be made available to other plant species after the tamarisk trees are removed. Hydrologic sampling is not a component of our monitoring system; however, qualitative observations will be made as the project progresses. Wildlife observations will also be made throughout the project. An interdisciplinary team will be used to complete the tamarisk eradication.

2.) *Describe the monitoring objective – brief statement identifying the specific site to be monitored, duration of monitoring and attribute or parameter monitored. If your project includes long-term monitoring, differentiate between the short term, contract objective (maximum contract period three years) and the long-term monitoring objective.*

The management objective of this project is to eradicate tamarisk from the 63 tributaries. An acceptable goal will be to decrease the tamarisk cover to 5% or less of the pre-eradication tamarisk cover in the project areas. The primary monitoring objective is to determine the change in vegetation at the sites. Specifically, we want to be able to look at the change in the native plant species in the area, and we predict an increase in native plant species' cover as they are released from competition with tamarisk for the available resources. Transects will be installed in at least 25% of these areas. The tributaries in which transects will be installed will be randomly selected. The canyons will be stratified into areas with <50 trees, and areas with more than 50 trees, based on the initial surveys completed by park staff. Further stratification may be necessary to ensure that canyons with more than 500 tamarisk are sufficiently represented in the monitoring program.

Tamarisk density will not be included in this monitoring system. Initial tamarisk density surveys have already been completed in some of these areas, and this information will be included in subsequent reports. To date, initial surveys have been completed in 49 of the 65 project areas. The remaining 16 surveys will be completed on the October monitoring trip. However, the total number of seedling, sapling and mature tamarisk trees removed from each tributary will be recorded as the eradication occurs. The post project surveys and follow-up maintenance will provide information about the success of the treatment. Sampling will not be necessary since total counts will be available. Photo points will be installed in each of the 63 tributaries. Pre- and post- treatment photos will be taken from these points. In addition, the beginning of each transect will be used as an additional photo point.

We believe that this project is not only feasible, but also that the rather basic monitoring system will be easy to install and will provide good data and allow the objectives to be met. The system may have to be altered if logistical problems are encountered or a better system is developed; we agree to notify the GCWC and AWPF of any changes to this monitoring plan or design prior to implementing those changes. The information generated by this project can be transferred to other southwestern areas, and could assist with management decisions.

3.) *Describe your monitoring strategy – it may be necessary to address each of the above listed objectives (from #2) separately.*

a. *Describe the appropriate attributes or parameters that you will use to measure whether you have obtained your objectives.*

We will look at vegetation cover to determine whether this project is successful. The primary objective is to eradicate the tamarisk from these areas and to allow native plant recolonization. This can be measured through change in vegetative cover. As each area is revisited 1-2 years following eradication, an exact count of tamarisk will be made as any new recruits or regrowth are encountered. This will aid with the determination of whether the eradication method was successful, or whether a different approach will be necessary in the future.

b. *Describe on or off-site features that may influence the monitoring design or data collection.*

The components of the monitoring program may have to be altered as the project is initiated. In some areas, the transect length may be too long and 25 meter or 50 meter transects will be used. In all cases, the transect lines will be long enough to cross most of the variability in the sampled vegetation. Transects will always be read during the fall, so seasonality should not affect the readings. Personnel will be trained in transect installation and completion to minimize observer error. Seasonal flooding has the potential to alter the data. For example, a flash flood during August 1999 scoured the vegetation in Stone Creek. If a transect had been installed prior to the flood, the data for the following years would be altered and that transect would not have been used in the study. Due to the remoteness of the area, data collection will be challenging. Every effort will be made to complete the transect installation on one river trip and to try to anticipate any logistical problems prior to the trip. There are certain variables that we cannot control that may influence the data collection (i.e. a rain event may prevent us from hiking into canyons due to safety concerns).

c. *Discuss how you will establish baseline conditions for the site. Baseline conditions characterize the pre-project site and are used for future comparisons. Therefore, measures and methods need to be replicable and should allow for determination of trend or change.*

The baseline conditions will be established by reading the transects prior to any eradication efforts. This data will be used as a baseline to judge future vegetation cover change from. The transects will be permanently installed, which will allow us to revisit the exact location in order to determine change over time. The total number of tamarisk in the tributary will be recorded as the eradication occurs. This will provide additional baseline data. Additional qualitative baseline data will be gathered for each canyon.

d. *What information will be generated and how will it help you quantify if you have achieved your objectives?*

This system will provide information about the change in vegetative cover over time. We will be able to detect whether we reach our goal of 5% or less tamarisk cover following eradication efforts. We will also be able to monitor the change in native plant species cover. One of the benefits the eradication work should provide is native vegetation reestablishment in these areas, and we will be able to detect these trends and changes with our monitoring system. We will also know whether the removal reduces colonization of tamarisk.

4.) *Describe data collection methods and/or sampling plan – include a map that notes the location of monitoring or sampling sites, and individual identifiers. (See folded map at end of report.)*

Quantitative monitoring

a. *Specify methods you will use to collect data.*

The type of transect will vary slightly depending on the area, but line transects will be used to measure vegetation cover. The standard transect length will be 50 meters, and the point intercept method will be used. A point will be read every 0.5 meters, which will provide 100 points per transect. The transect length may be too long in some of the spring areas, and may need to be reevaluated; however, there will always be 100 points per transect read regardless of the length. All vegetation touching the point will be counted. This will allow us to determine vegetation cover. Each transect will be considered a sampling unit, and these will be compared to themselves each year to detect change in vegetation cover. In each of the selected tributaries, one to three 50 meter transects will be installed. In each of the transects, we want to detect a 5% change in vegetation cover following the removal efforts. The transect will be read prior to eradication, and then each year following eradication (for the project duration), which will help us to determine if native plant cover increases following the removal of tamarisk trees. These transects will be permanently installed, which will allow the park to monitor vegetation change past the duration of this project.

b. *List equipment you will use to collect data.*

Compass, 50 meter tapes, range pole / tent pole as a pointer, camera, film, data sheets, stakes to mark transect location, GPS unit.

c. *Describe how sampling sites will be selected.*

Transects will be installed in at least 16 of the 63 tributaries. The tributaries will be stratified based on initial surveys (into areas with <50 trees and more than 50 trees), and then the areas will be randomly selected. The 16 areas that have not been surveyed will be included in the overall selection process, and the assumption that the springs and small canyons have less than 50 trees and the remaining canyons have greater than 50. The number of the 16 selected areas in each category will be based on the percentage of the total areas with less than or more than 50 trees. For example, if 75% of the 63 areas have greater than 50 trees, than 12 of the randomly selected areas will be from that pool. In each of the selected tributaries, one to three transects will be installed, depending on the extent of the population. The transects will be located in the beginning, middle and end stretches of the tamarisk infested areas. The beginning point of the transect and the bearing will be randomly selected in the field.

d. *List the number of sampling sites needed and how you have determined the appropriate number of sites.*

We estimate that the installation of transects in 25% of the 63 tributaries will provide as adequate measure of the change in cover. Once data is collected from 16 areas, we will have a good basis to judge whether additional transects will be necessary. If more transects are needed, they will be installed on a subsequent trip. Since this monitoring plan aims to detect change in vegetative cover over time, each transect will be compared to itself in future years. At this time, we don't believe it is necessary to install transects in more than 25% of the tributaries.

e. *Specify when you will collect data, how often you will collect data and how long you will collect data. Is data collection period sufficient to be able to determine desired trend or changes?*

Data will be collected from transects installed in the 16 selected tributaries. The data will be collected prior to any eradication work, and the pre-eradication monitoring report will be completed by the end of December, 2000 and this will be used as baseline data. The transects will be re-read after eradication work, annually, for the duration of this project. The transects will be revisited during the same month as they were installed. The monitoring system will provide information about short-term vegetation change following eradication, and will also be used for long-term monitoring that will continue past the completion of this project.

f. *Describe how data will be analyzed. If using statistical analysis, include acceptable level of false change error rate, acceptable level or power and magnitude of change you want to detect.*

In our design, each transect or group of points is a sampling unit, and they will be randomly located during the first year, and then re-measured during subsequent years. Since the samples are not independent, a paired t-test will be used. This is a powerful device for detecting change over time . When we compare more than 2 years, we will apply the Bonferroni adjustment to the threshold p-value. This procedure is used when the number of comparisons is few and it is part of the t-test analysis (Glantz 1992). The confidence interval in this analysis will be 95%. We want to be able to detect a 5% change in total vegetation cover, which is slightly different than the goal of 5% or less than the original tamarisk cover present in the area.

Qualitative monitoring

a. *Photo point monitoring – see photo monitoring procedures.*

Photo points will be installed in each of the tributaries prior to the eradication work. These points will be subjectively selected and will typify the vegetation characteristics of the area. The photographs will be taken prior to eradication, immediately following eradication, and then every year for the project duration. The point will be permanently located, which will allow the park to continue long-term monitoring efforts after this project is completed. In addition, the beginning of each transect will serve as a photo point. The permanent photo point format provided by AWPF will be used to record this information.

b. *Describe type of qualitative monitoring to be conducted and procedures to be employed.*

We have already initiated qualitative monitoring in the majority of the 63 tributaries. We have made initial assessments of most of the areas and counted approximate numbers of seedlings, saplings and mature tamarisk trees that occur. This was primarily done in order to estimate the number of people and time necessary for the eradication work;

however, this information provides good baseline data for this project. In order to determine whether the treatment is effective, the tamarisk will be counted as the eradication occurs. Visits during the following years, and a new count as the follow up maintenance occurs, will help to judge the effectiveness of the treatment. Hydrologic changes will be observed and recorded, but at this point specific sampling will not be included in the monitoring system.

More thorough site condition assessments will be completed as the project begins. Geologic, hydrologic, and additional biological information will be recorded. The format used for the initial habitat assessments will be used; please refer to the attached example of this data sheet. Plant species lists will be compiled for each of the tributaries. Where possible, the boundaries of tamarisk populations will be mapped with a GPS unit. In some areas, this may not be feasible due to the extreme nature of the topography.

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SECTION 5: PRE-REVEGETATION AND INITIAL POST-REVEGETATION AVIAN CENSUSING AT LEES FERRY

By Lawrence E. Stevens

Justification

Birds are excellent, conspicuous and well-known indicators of habitat quality and dynamically change in response to stand and environmental changes (Brown et al. 1987, Stevens et al. 1997). Pre-treatment and post-treatment avian monitoring was conducted to determine the effect of tamarisk control on bird populations in the Lees Ferry area. The treated stand at Lees Ferry including approximately 4 ha of tamarisk and arrowweed (*Tessaria sericea*) habitat, with scattered native woody shrubs was compared to the control site at Paria Beach, located 1.5 km downstream at Mile 1.0R. The Paria Beach site includes about 3 ha of dense tamarisk habitat with marginal coyote willow (*Salix exigua*).

Methods

ACQUISITION OF HISTORICAL DATA

Historical data have been obtained from the Grand Canyon Monitoring and Research Center, the Glen Canyon National Recreation Area, and L.E. Stevens' personal data archives over the past decade. A total of 116 bird species were detected in the Lees Ferry area from January 1994 to June 1999 (J. Spence, Ecologist, Glen Canyon National Recreation Area, Page, AZ) and Stevens et al. (1997). The Glen Canyon National Recreation Area data revealed an average of 10.5 bird species (sd = 4.07 species) were detected per survey in the overall Lees Ferry area, with a mean bird species detection rate of 13.7 (sd = 7.09) birds/hr for 177 surveys. This same database revealed that, on average, 36.3 (sd = 34.2) birds were observed/survey, with a mean bird detection rate of 45.9 (sd = 37.8) birds detected/hr.

Stevens et al. (1997) examined waterbird distribution, and included a study site at Lees Ferry. They reported that impoundment impacts override natural, reach-based channel geomorpholgy influences on seasonal waterbird distribution in the Grand Canyon along the Colorado River downstream from Glen Canyon Dam. Interviews with pre-dam observers and historic literature indicate that winter waterbird concentrations did not occur prior to completion of Glen Canyon Dam (1963), and that pre-dam summer breeding was rare. River corridor surveys from 1973 through 1994 detected 25 species of diving and dabbling waterfowl, and 33 other wading, shorebird and water-associated raptor species, with a grand mean of 678.7 waterbirds/trip. The post-dam assemblage was dominated by Anseriformes (13 diving and 12 dabbling species).

Winter bald eagle (*Haliaeetus leucocephalus*) concentrations and summer breeding mallard (*Anas platyrhynchos*) populations occurred, but wading birds and shorebirds occurred primarily as migrants or summer vagrants. Winter waterfowl AARE (area-adjusted rate of encounter) values decreased downstream by 3 orders of magnitude from the clearwater Glen Canyon reach to the usually turbid middle and lower Grand Canyon reaches. Summer waterfowl AARE were equivalent in wide and narrow reaches upstream from the Little Colorado River (LCR), but decreased abruptly downstream. Waterfowl densities were greatest in the highly productive clearwater and variably turbid segments upstream from the Little Colorado River, but were negatively correlated with reach width. These influences resulted in a non-linear (circuitous) alteration in the assemblage over distance downstream from the dam. Dam operations that limit food and habitat resources may limit waterbird distributions. In addition, Brown et al. (1998) reported that human disturbance from boats and activity reduced wintering bald eagle presence in the study area around Lees Ferry.

SITE PHOTOGRAPHY

Recent aerial photographs were obtained from the Bureau of Reclamation and used to develop a site map of the Lees Ferry area (Fig. 7.1). Oblique photographs have been taken at fixed points on each survey site during the summer, and according to the standards established by AWPF.

STUDY SITES

The treated stand at Lees Ferry includes approximately 4 ha of tamarisk and arrowweed (*Tessaria sericea*) habitat, with scattered native woody shrubs. The control site at Paria Beach is located 1.5 km downstream at Mile 1.0R, and includes about 3 ha of dense tamarisk habitat with marginal coyote willow (*Salix exigua*).

The avian monitoring transects are each approximately 200 m in length on each of the two sites, and have been monitored during 10 sites visits from July-November 2000 during the pre-treatment period. The transects run the full length of the treated area and the control site, and pass longitudinally through the sites.

FIELD DATA COLLECTION

Avian census data collection consisted of a timed (at least 30 min) walks on each transect, with regular one-two minute stops to detect all birds on the site, along the periphery, and flying overhead. Site visits were generally conducted during morning hours. A total of 12 pairs of surveys were conducted from late May 2000 to 4 February 2001, along with several unpaired surveys (31 May and 8 August 2000 on the Lees Ferry stand only, and 11 October on the Paria Beach stand only), for a total of 23 pre-treatment surveys. Following tamarisk removal from the site, the author conducted paired surveys on the two sites, but distinguished treated land from the peripheral land on the Lees Ferry site. The author conducted a total of 13 pairs of surveys using the same techniques as described for the pre-treatment monitoring from 16 February through October 2001, for a total of 26 post-treatment surveys in 2001.

These data represent an index of avifaunal abundance and diversity at each site during each visit. Data are recorded in a field book, and include the time of day, weather conditions (temperature, wind speed, cloud cover, precipitation), the observer, the location on the transect, the identity and number of all birds detected, and any other pertinent observations.

DATA COMPILATION

Data are compiled into an Excel spreadsheet (Table 5.1).

STATISTICAL ANALYSES

Analysis for this task included linear regression and paired comparisons of control and treatment plot avian abundance and diversity data. The number of birds seen on the plot and the number of bird species were converted to detection rate data by adjusting for the number of hours of observation. In addition to developing regression relationships between the treated and untreated plot data, the paired plot data are analyzed using the nonparametric tests to determine whether consistent differences exist between the control and treated sites. The significance criteria were adjusted in these analyses using the serial Bonferroni approach (Rice 1989) because multiple pair-wise tests are conducted on a single data set.

Results and Discussion

THE PRE-TREATMENT ASSEMBLAGE

A total of 61 bird species were detected on and in the immediate vicinity of, the two study sites in the summer and fall of 2000 during 13 paired surveys and several ancillary site visits. The summer assemblage at both sites was dominated by House Finch and Bewick's Wren, with 1-2 pairs each of Say's Phoebe, Blue Grosbeak, and Northern Oriole, and resting Violet-green and Northern Rough-winged Swallows. The autumn assemblage was initially dominated by Lark Sparrow, and subsequently by Vesper Sparrow, with several Blue-gray Gnatcatchers, Northern Flickers and, at Paria Beach, Lazuli Buntings. The winter assemblage at both sites is strongly dominated by White-crowned Sparrows and Ruby-crowned Kinglets, with minor presence of Bushtits and Mountain Chickadees.

COMPARISON OF THE TWO SITES

Tables 5.1 and 5.2 present the raw abundance avifaunal data, and the rate of individual and species detection during the pre-treatment period in 2000 and 2001. The mean pre-treatment avian species detection rate was 10.4 and 9.2 species detected/hr on the Lees Ferry and Paria Beach study sites, respectively. The 13 pairs of pre-treatment bird surveys show that the mean number of birds detected/hr (excluding birds that flew over the plots) was 49.5 birds/hr and 23.2 birds/hr prior to treatment for the Lees Ferry and Paria Beach sites, respectively. Only the total number of birds detected differed significantly between sites, probably related to a species-area effect stemming from the larger size of the Lees Ferry site.

The pre-treatment Lees Ferry site consistently had higher raw numbers of birds than did the Paria Beach site (Wilcoxon $t = 1.5$, $Z = 2.488$, $n = 9$ pairs, $p = 0.0129$). This was the only statistically significant variable among the abundance and diversity and detection rate variables examined using the serial Bonferroni adjustment of significance criteria for multiple tests from a single data set. This difference was undoubtedly related to the greater size of the Lees Ferry stand, a species area effect that will be more fully explored in subsequent reports; area adjustment of abundance is likely to render between site differences non-significant. Collectively, these results indicate that the two sites have comparable avian occupation.

Regression analyses revealed that positive relationships exist between the two sites for avian raw abundance, detection rate/hr of observation, raw diversity and rate of species detection/hr. Avian species detection rates varied similarly over time (Fig. 5.1), although abundance was not closely related between the two sites (Fig. 5.2). Only the relationship between the species detection rate was statistically significant between the two study sites.

Table 5.1: Total abundance of birds by species encountered in and around the treated and control tamarisk stands near Lees Ferry, Arizona, May 2000-October 2001. Data are compiled from 23 pre-treatment surveys and 26 post-treatment surveys. LF - Lees Ferry; LF-Trt – LF tamarisk removal site; PB - Paria Beach. Data represent total raw abundance detections on each site. Species without abundance data were detected near, but off, the study plots.

		Pre-Treatment		Post-treatment		
Species	**Scientific Name**	**LF**	**PB**	**LF-Trt**	**LF=All**	**PB**
Pied-billed Grebe	*Podilymbus podiceps*	---	---	---	---	---
Grebe sp.	*Podiceps* sp.	1	0	0	0	0
American Coot	*Fulica americana*	4	0	0	0	0
Great Blue Heron	*Ardea herodias*	3	1	3	3	0
Snowy Egret	*Egreta thula*	---	---	---	---	---
BC Nightheron	*Nycticorax nycticorax*	---	---	1	1	0
Mallard	*Anas platyrhynchos*	22	0	28	28	0
Gadwall	*Anas strepera*	41	0	0	0	0
American Wigeon	*Anas americana*	37	0	0	0	0
Northern Pintail	*Anas acuta*	2	0	0	0	0
Lesser Scaup	*Athaya affinis*	---	---	---	---	---
Redhead	*Athya americana*	---	---	---	---	---
Bufflehead	*Bucephala albeola*	6	0	0	0	0
Unk. Dabblers	*Anatidae sp.*	---	---	---	---	---
Red-tailed Hawk	*Buteo jamaicensis*	0	1	0	0	0
Northern Harrier	*Circus cyaneus*	1	0	0	0	0
Osprey	*Pandion halietus*	---	---	---	---	---
Sharp-shinned Hawk	*Accipiter striatus*	0	2	0	0	0
Coopers Hawk	*Accipiter cooperi*	---	---	---	---	---
Peregrin Falcon	*Falco peregrinus*	1	2	0	0	0
Killdeer	*Charadrius vociferus*	0	0	1	1	1
Spotted Sandpiper	*Actitis macularia*	0	1	0	0	0
Common Snipe	*Gallinago gallinago*	1	0	0	0	0
No. Sawwhet Owl	*Aegolius acadicus*	0	0	1	1	0
GH Owl	*Bubo virginianus*	0	0	0	0	1
Belted Kingfisher	*Ceryle alcyon*	1	0	1	1	0
Mourning Dove	*Zenaida macroura*	1	8	3	3	4
Northern Flicker	*Colaptes cafer*	6	4	0	0	0
Red-naped sapsucker	*Sphyrapicus nuchalis*	0	1	0	0	0
BC Hummingbird	*Archilochus alexanrei*	0	0	0	1	10
White-throated Swift	*Aeronautes saxatilis*	---	---	---	---	---
Ash-throated Flycatcher	*Myiarchus cinerascens*	8	3	3	3	10
Say's Phoebe	*Sayornis sayi*	0	1	2	2	0
Black Phoebe	*Sayornis nigricans*	1	2	0	0	1
Cordilleran? Flycatcher	*Empidonax occidentalis*	0	1	0	0	0
Empidonax sp.	*Empidonax sp.*	2	0	0	0	0
Violet-green Swallow	*Tachycineta thalissina*	5	4	0	0	6
Northern Rough-winged Swallow	*Stelgidopteryx serripenis*	4	5	0	0	2
Common Raven	*Corvus corax*	11	3	0	3	0
Scrub Jay	*Aphelocoma coerulescens*	---	---	---	---	---

Loggerhead Shrike	*Lanius ludovicinaus*	2	0	0	0	0
Common Bushtit	*Psaltriparus minimus*	29	0	0	0	4
Bewick's Wren	*Thryomanes bewickii*	21	8	0	0	12
Canyon Wren	*Catherpes mexicanus*	12	6	0	0	2
Rock Wren	*Salpinctes obsoletus*	---	---	---	---	---
Marsh Wren	*Cistothorus palustris*	4	0	9	9	0
Golden-crowned Kinglet	*Regulus satrapa*	---	---	---	---	---
Ruby-crowned Kinglet	*Regulus calendula*	9	4	0	0	4
Blue-gray Gnatcatcher	*Polioptila caerulea*	6	1	1	1	4
Mountain Chickadee	*Parus gambeli*	0	1	0	0	0
Vireo sp.	*Vireo sp.*	1	0	0	0	0
Lucy's Warbler	*Vermivora luciae*	0	0	0	0	17
Yellow Warbler	*Dendroica petechia*	3	2	0	0	13
Yellow-rumped Warbler	*Dendroica coronata*	2	2	0	0	0
Common Yellowthroat	*Geothypis trichas*	0	0	2	2	0
Yellow-breasted Chat	*Icteria virens*	---	---	---	---	---
Warbler sp.	*Warbler sp.*	16	2	0	0	0
Loggerhead Shrike	*Lanius ludovicianus*	---	---	---	---	---
No. Mockingbird	*Mimus polyglottos*	---	---	---	---	---
Brown-headed Cowbird	*Molothrus ater*	2	0	15	15	13
Red-winged Blackbird	*Agelaius phoeniceus*	3	0	0	0	0
Northern Oriole	*Icterus bullocki*	1	1	1	0	0
Hooded Oriole	*Icteras cucullatus*	0	0	0	1	0
Great-tailed Grackle	*Quiscalus mexicanus*	1	0	13	13	11
YH Blackbird	*Xanthocephalus xanthocephalus*	0	0	0	1	0
Western Tanager	*Piranga ludoviciana*	0	2	0	0	2
Blue Grosbeak	*Guiraca caerulea*	6	1	2	2	8
Black-headed Grosbeak	*Pheuticus melanocephalus*	0	1	0	0	0
Lazuli Bunting	*Passerina amoena*	0	5	0	0	5
Bunting sp.	*Passerina* sp.	3	4	0	0	1
Lesser Goldfinch	*Carduelis psaltria*	8	18	3	3	0
House Finch	*Carpodacus mexicanus*	28	9	0	0	8
Dark-eyed Junco	*Junco hyemalis*	2	15	0	0	6
White-crowned Sparrow	*Zonotrichia leucophrys*	55	19	50	55	7
Vesper Sparrow	*Pooecetes gramineus*	37	28	1	1	4
Lark Sparrow	*Chondestes grammacus*	28	4	1	1	0
Black-throated Sparrow	*Amphispiza bilineata*	---	---	---	---	---
Lincoln Sparrow	*Melospiza lincolnii*	16	2	3	3	0
Unknown Sparrow	Sparrow sp.	6	2	0	0	13
Unknown Passerine	*Passerine* sp.	2	0	0	0	2

Table 5.2: Bird species and abundance detection rates by date for the overall Lees Ferry (LF), the treated LF plot, and the Paria Beach (PB) study sites from May 2000 through October 2001.

Date	Tot S/hr: LF-All	LF-Trt	PB	Tot Abun/hr: LF-All	LF-Trt	PB
31-May-00	10.50			25.50		
16-Jul-00	5.65		5.14	33.18		8.57
30-Jul-00	10.80		14.40	31.20		21.60
2-Aug-00	13.33		18.00	32.00		26.00
8-Aug-00	13.09			30.55		
18-Aug-00	20.00		12.00	38.00		30.00
6-Sep-00	11.08		12.00	48.00		43.00
30-Sep-00	10.15		12.00	43.38		27.00
11-Oct-00			6.00			10.50
24-Oct-00	10.00		12.00	49.00		36.00
18-Nov-00	17.14		9.60	192.00		31.20
30-Nov-00	8.40		4.00	37.20		10.00
17-Dec-00	8.57		5.14	45.43		27.43
4-Jan-01	5.33		5.14	51.33		12.00
4-Feb-01	4.80		3.60	16.80		18.00
16-Feb-01	4.36	0.00	6.00	12.00	0.00	12.00
6-Mar-01	4.80	0.00	4.00	4.80	0.00	8.00
13-Apr-01	4.80	0.00	9.60	8.40	0.00	20.40
26-Apr-01	6.00	1.20	7.20	25.20	1.20	14.40
3-May-01	2.00	1.00	10.15	3.00	2.00	17.54
19-May-01	6.00	1.20	8.57	30.00	1.20	16.29
28-May-01	3.00	0.60	8.40	4.20	0.60	24.00
9-Jun-01	0.00	0.00	10.67	0.00	0.00	17.33
19-Jun-01	3.43	0.00	8.57	3.43	0.00	15.43
29-Jun-01	0.00	0.00	2.40	0.00	0.00	2.40
26-Jul-01	1.33	0.00	10.80	1.33	0.00	22.80
26-Aug-01	6.00	1.20	12.00	20.40	1.20	34.50
29-Oct-01	5.45	2.18	1.33	66.55	7.64	1.33

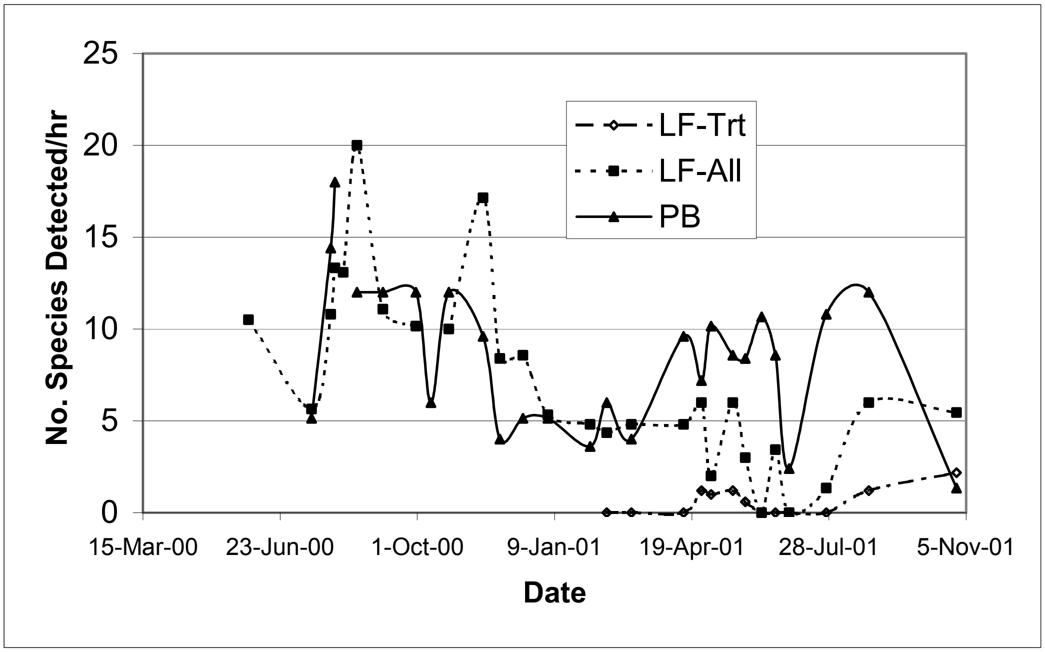

Figure 5.1: Bird species rate (number detected/hr) at Lees Ferry (filled squares), on the treated plot (open diamonds), and Paria Beach (filled triangles) from May 2000 through October 2001.

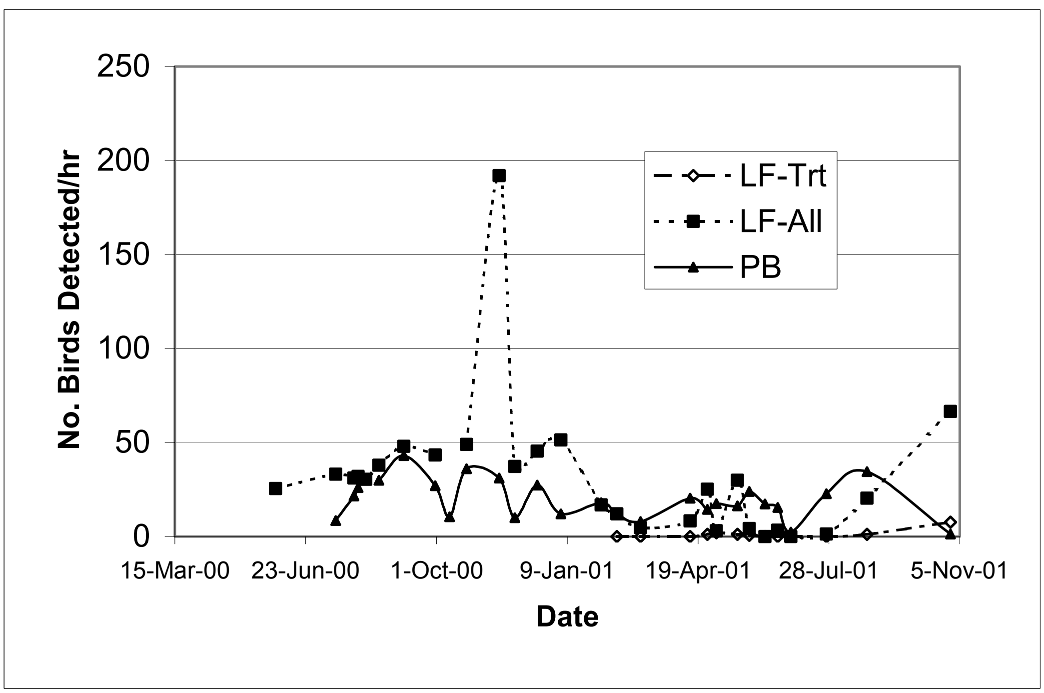

Figure 5.2: Avian detection rate (number of birds detected/hr) on the overall Lees Ferry (filled squares), the LF-treated (open diamonds), and Paria Beach (filled triangles) study sites from May 2000 through October 2001.

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SECTION 6: PRE-TAMARISK ERADICATION MONITORING IN THE COLORADO RIVER TRIBUTARIES

By Lori Makarick

Executive Summary

The first of six river trips was conducted in October 2000. The purpose of the first trip was to complete initial surveys for tamarisk in the project areas, to install long-term vegetation monitoring transects and photo points, to complete habitat assessments for southwestern willow flycatcher in the project areas, and to discuss and evaluate logistics of future eradication trips. This section summarizes the first river trip, led by the National Park Service-Grand Canyon National Park Science Center in cooperation with Grand Canyon Wildlands.

Trip Logistics

The first river trip was scheduled from October 13-30, 2000, with an exchange at Phantom Ranch on October 20. Four 18-foot oar boats were used on the trip, which were rented from the Park. Trip participants were:

Lori Makarick, project leader, Grand Canyon National Park
Dave Desrosiers, trip leader, Grand Canyon National Park
Tim Stephenson, boatman and project assistant
Matt Vandzura, boatman, Grand Canyon National Park
Bryan Edwards, boatman, Grand Canyon National Park
Simone Sellin, cook and project assistant
Eric North, project assistant, Grand Canyon Wildlands Council
Kelly Burke, project assistant, Grand Canyon Wildlands Council
Chris Moore, project assistant, Yellowstone National Park
Fred Phillips, project assistant, Fred Phillips Consulting
John Grahame, project assistant, certified Southwestern willow flycatcher biologist
Selinda Border, project assistant, Arizona Water Protection Fund
Dave Christiana, project assistant, Arizona Water Protection Fund
Roy Zipp, project assistant, Big Thicket National Park
Rachel Stanton, project leader, Grand Canyon National Park
Boone Vandzura, project assistant, Yellowstone National Park

The weather on the upper half of the trip was perfect, with sunny, warm days and beautiful starry nights. During the lower half of the trip, a cold front moved in and there were many days of rain. The highlight of the trip was below Havasu Canyon as hundreds of new waterfalls emerged along the river corridor. The beauty of the canyon far surpassed the discomfort of freezing cold and wet clothes. Many side canyons flash flooded during the trip, including Diamond Creek which is the location of the de-rig and take out. The trip schedule was altered so that the boats could reach Diamond Creek a day early to determine whether a takeout was possible. The Hualapai rangers had left a note at the takeout location saying that the road was closed, so park rangers on the trip contacted the park with a satellite phone to make alternative takeout plans. The trip had to continue downstream and take out at Pearce Ferry, on Lake Mead. Park rangers stationed at Lake Mead brought two motorboats up river, and towed the 4 oar boats out to Pearce Ferry. This saved 2 days of rowing and enabled the trip to be back on the South Rim on October 30 as planned. The final few days of the trip were long, but with 95% of the scheduled work completed under inclement weather conditions, all participants were content.

Methods

TAMARISK SURVEYS

Tamarisk surveys were conducted in all of the tributaries on the approved list, with the exception of Pipe Creek and the Cave Springs area. Pipe Creek was accessed from the South Rim and the survey was completed by January 2001. Survey crews hiked as far up the tributaries as logistically possible and counted all tamarisk trees. Tree counts were broken down into the following categories:

Seedling - Newly emerged plants up to 1m tall
Sapling - Plants >1m tall and with less than 5cm diameter at the base of the trunk
Mature - Plants >1m tall and with greater than 5cm diameter at the base of the trunk, or with multiple branching at the base of the trunk

Note that the category of seedling is not the strict botanical definition of the term, which means that the cotyledon is still attached to the emerging plant. For the purposes of the surveys, seedling denotes a plant that could be manually removed, either by hand or with a weed wrench.

Survey crews also recorded ancillary data about the canyons, such as general information about the canyon and access from the river. The surveys were designed to provide the baseline information necessary for the future eradication trips. Work schedules and trip itineraries could be efficiently designed with this data. Please refer to *Appendix 6A: Initial Tamarisk Survey Data* for the complete data set.

Surveys revealed that the majority of the tamarisk in side canyons are seedlings, which can be manually removed. This eradication project was very timely and occured while control was still feasible. A summary of the survey data follows:

Category	Total Number	Percentage of Total
Seedlings	18,332	79%
Saplings	2,607	11%
Mature	2,216	10%
TOTAL	23,155	100%

In some tributaries, tamarisk numbers were estimated. For example, there were thousands of seedlings in Soap Creek and counting each individual was not feasible. Seedlings were counted in small areas, and that estimate extrapolated to the larger area. In general, each individual sapling and mature tree was counted. While this provided excellent baseline data, complete counts were made during the eradication efforts. The data from these surveys were subject to change between data collection and the eradication trips. If there was a dry winter and spring, many of the seedlings might not have survived. Flash flooding is possible at any time during the year, and the entire canyon may be scoured and left devoid of vegetation following the flood. With this in mind, the park had good data that was used to plan the work for the following 2 years.

TRANSECT DATA COLLECTION

As stated in the monitoring plan, vegetation cover data is used to determine the project success. Transect data was collected in at least 25% (16 tributaries) throughout this project, which should provide an adequate measure of change in cover percentages. Locations were selected through a random process prior to the first trip. The tributaries were stratified based on initial survey data. The stratification ensured that an adequate sample of canyons with greater than 50 tamarisk and less than or equal to 50 tamarisk was represented in the overall design. Initial data from the 63 tributaries is described below:

Areas with ≥ 50	38	60%	10 transects
Areas with < 50	25	40%	6 transects

All of the canyon names were printed on pieces of paper and placed in two groups. Ten canyon names were blind selected from the areas with ≥ 50 tamarisk, and six canyon names were blind selected from the other group. This simple process allowed for random selection of the transect locations. The following canyons were selected:

Soap Creek	11 R
Carbon Creek	64.7 R
Lava Chuar Canyon	65.5 R
Serpentine Canyon	106 L
Hotauta Canyon	107.8 R
Waltenberg Canyon	112 R
Elves Chasm	116 L
Bighorn Wash	117 L
Lower Blacktail	120 R
Forster Canyon	122.7 L
Specter Canyon	129 L
133 Mile Creek	133 R
Cranberry Canyon	138.5 R
Last Chance Canyon	155.5 R
Lower Cove Canyon	174 R
Trail Canyon	219 R

Seventy-four mile canyon was initially selected but was rejected because there are only 4 trees, which were located high up in a bowl that would make transect installation impossible. 133 mile Creek was randomly selected as a replacement. The selection process worked well; however there is a grouping of 8 transect locations within 20 river miles which made the trip logistics difficult.

The number of transects installed in each area was based on the extent of the tamarisk populations, with the goal of installing 1 to 3 transects in each area. The location of each transect was stratified so that populations of tamarisk would be bisected; therefore, the transect location was not randomly selected in each tributary. Once populations were encountered, a start point was selected and the 50m tape was laid out and the bearing was recorded. GPS readings were taken at the start and end point of the transects (when there was satellite coverage) so that relocation of the transects would be easier. The GPS unit was also used to get an accurate distance from the river reading. Photographs were taken from the start and end points of each transect, and also of the beginning of the transect, again for ease of relocation. The photographs will be further described in the Photopoint section of this report.

Line transects with the point intercept method were used to measure vegetation cover. The transects were 50 meters long, with a point read every 0.5 meters. A total of 100 hits were recorded for each transect. A 2m long, 1cm in diameter pole was used as the point, and all vegetation or litter touching the point was recorded. With this technique it is important to understand that it is possible to have greater than 100% cover when all the species are added together since there are often more than 100 total hits along each transect line. The following general categories and their attributes were used in data collection:

- Rock - Small pieces of gravel to boulders or bedrock/schist.
- Bare Ground - No cover on the ground; pea-sized gravel was counted in this category too.
- Brush - Dead vegetation larger than 2cm in diameter. This was primarily dead and down tamarisk in the transects.
- Litter - Dead vegetation smaller than 2cm in diameter. This was primarily leaf litter and grass growth from previous years.
- Soil Crust - Microbiotic soil layers.
- Water - Differentiated into perennial streams and pools, and ephemeral puddles and pools from the precipitation that was encountered on the trip.

Along the transects, 31 different plant species were encountered. For ease of recording and to make this report readable, common names were used. Table 6.1 below (*Plant Species Encountered Along Transects*) lists all of the plant species that occurred in the transects, along with their scientific name and the family name. There were 2 unknown forbs encountered and 1 unknown grass, and because of the lack of floral parts accurate identification was not possible.

Table 6.1 - Plant Species Encountered Along Transects

Common Name	**Scientific Name**	**Family Name**
Acacia	*Acacia greggii* Gray var. *arizonica* Isely.	Fabaceae
Arrowweed	*Tessaria sericea* (Nutt) Shinners.	Asteraceae
Baccharis	*Baccharis emoryi* Gary.	Asteraceae
Brickellia	*Brickellia longifolia* Wats.	Asteraceae
Brittle bush	*Encelia farinosa* Gray.	Asteraceae
Buffalo berry	*Sherherdia rotundifolia* Parry.	Elaeagnaceae
Burro weed	*Happlopappus salicinus* Blake.	Asteraceae
Cane bluestem	*Bothriochloa barbinodis* (Lag.) Herter	Poaceae
Cassia	*Senna covesii* (Gray) Irwin & Barneby	Fabaceae
Cattail	*Typha* sp.	Typhaceae
Cottonwood	*Populus fremontii* Wats.	Salicaceae
Coyote willow	*Salix exigua* Nutt.	Salicaceae
Desert broom	*Baccharis sarothroides* Gray.	Asteraceae

Desert trumpet	*Eriogonum inflatum* Torr. & Frem.	Polygonaceae
Ephedra	*Ephedra nevadensis* Wats.	Ephedraceae
Galleta grass	*Hilaria jamesii* (Torr.) Benth.	Poaceae
Happlopappus	*Happlopappus acradenius* (Greene) Blake	Asteraceae
Maidenhair fern	*Adiantum capillus-veneris* L.	Adiantaceae
Mesquite	*Prosopis glandulosa* Torr. Var. *torreyana* (Benson) M.C. Johnst.	Fabaceae
Phragmites	*Phragmites australis* (Cav.) Trin. Ex Steud.	Poaceae
Poreleaf	*Porophyllum gracile* Benth.	Asteraceae
Rush	*Juncus* sp.	Juncaceae
Sacred datura	*Datura meteloides* DC.	Solanaceae
Sand dropseed	*Sporobolus crytandrus* (Torr.) Gray.	Poaceae
Satintail	*Imperata brevifolia* Vasey.	Poaceae
Saw grass	*Cladium californicum* (Wats.) O'Neill.	Cyperaceae
Scratchgrass	*Muhlenbergia asperifolia* (Nees & Mey.) Parodi.	Poaceae
Seep willow	*Baccharis salicifolia* (R. & P.) Pers.	Asteraceae
Silver beardgrass	*Bothriochloa saccharoides* (Swartz) Rydb.	Poaceae
Tamarisk	*Tamarix ramossisima* Deneb.	Tamaricaceae
Three awn	*Aristida arizonica* Vasey.	Poaceae

Due to the extreme weather on the lower portion of the trip, transects were not installed in 133 Mile Creek and Trail Canyon. These transects were installed on the first eradication trip. A total of 31 transects were installed. Three transects were installed in Carbon Creek, Lava Chuar Canyon. Two transects were installed in Serpentine Canyon, Specter Canyon and Cove Canyon. And one transect was installed in each of the remaining canyons. In addition to the installation of transects in 133 Mile Creek and Trail Canyon, we recommended that an additional 1-2 transects be installed in Soap Creek. Time constraints on this trip did not allow for that work to be completed.

Please refer to Appendix 6B - *Transect Data for Tamarisk Eradication Project* for the complete data set. In Appendix 6B, the total percentage for each of the categories and for each individual plant species is recorded. Additional information about each transect, such as the end point GPS readings and general descriptions of the location, are included.

Please refer to Appendix 6C - *Transect Data Summary* for a chart that condenses the transect data for all of the transect locations. Once the eradication efforts are completed in the areas, the transects were re-read and the change in vegetation cover was analyzed. Comparison between the canyons is very difficult due to the high variation in plant species composition in the areas. However, along each transect we were able to describe cover changes following eradication. In canyons with more than one transect, additional analyses could be completed. Statistical analyses at this point were not possible, but a summary of the data is provided in Table 6.2 (*Transect Data Synopsis*) below.

Table 6.2 - Transect Data Summary

	Soap 1	Carbon 1	Carbon 2	Carbon 3	Lava Chuar 1	Lava Chuar 2	Lava Chuar 3	Serpentine 1	Serpentine 2	Hotauta 1	Waltenberg 1	Elves 1	Bighorn Wash	Blacktail 1	Forster 1	Specter 1	Specter 2	Cranberry 1	Last Chance 1	Cove 1	Cove 2	**Average %**
Total Vegetation	27	22	20	130	21	17	58	21	34	8	15	19	128	5	17	13	64	51	33	55	37	37.9
Rock & Bare Ground	75	70	79	0	75	80	45	72	64	86	89	75	18	95	88	90	51	54	27	47	45	63
Brush	3	12	4	5	0	0	2	18	5	0	1	3	8	0	0	0	0	1	1	7	7	3.7
Soil Crust	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0.4
Litter	7	18	7	77	12	8	36	3	13	10	4	1	33	0	2	0	22	30	5	10	25	15.4
Water	0	0	0	0	0	0	0	0	0	0	1	10	3	2	0	3	1	0	1	0	1	1.1
Tamarisk	20	19	19	93	20	17	38	6	13	8	14	14	7	5	17	12	23	4	19	52	30	21.4
Total Hits	112	247	221	461	217	210	302	241	250	208	221	221	501	204	214	213	313	335	148	241	237	258.9
Percent Composition of Tamarisk of Total Vegetation	74	86	95	72	95	100	66	29	38	100	93	74	5.5	100	100	92	36	7.8	58	95	81	56.6
Percent Composition of Tamarisk of Total Transect Hits	18	16	17	44	19	16	27	5.3	11	7.7	13	13	3.7	4.9	16	11	17	2.8	28	44	26	17.7

Along the transects, the percent composition of tamarisk was high, ranging from 5.5 to 100 percent, with an average of 56.6%. The transects are not necessarily representative of the vegetation composition of the tributary since the placement was stratified. Many of the tamarisk occur within the creek beds or washes, and in those areas there is a high amount of rock and bare ground.

It would be valuable to install additional transects in each canyon, with randomly selected locations in order to compare the composition. However, that is beyond the scope of this monitoring plan because of the time and personnel necessary to complete that work. For the purposes of this project, the installed transects will provide the information about how vegetation changes over time in the project area.

PHOTO POINT INSTALLATION

A goal of the monitoring plan was to install photo points in each of the 63 tributaries. During the first trip, a total of 70 photo points were installed in 25 of the tributaries. A total of 167 photographs were taken as part of the photo point monitoring portion of this project. From many of the photo points, several views were taken in order to better typify the vegetation characteristics of the area. Photo points were also installed at the beginning and end points of the transects. Whenever there was adequate satellite coverage, GPS readings were taken from the photo point. Along with the permanent photo points, additional photographs were taken to help with the relocation of the transects. The photopoint forms provided by the Arizona Water Protection Fund were used to record data. The data is summarized in Appendix 6D - *Photopoint Data for Tamarisk Eradication Project.* The data summary includes the majority of the information requested on the photo point forms. The photo points were named for each project area and then consecutively numbered. For example, the second view from the third photo point installed in Carbon Creek is labeled Carbon Creek 3 View 2. The extra photographs primarily used for site relocation purposes are included in the summary table; those photographs are given the same photo point area name, but they are then alphabetically labeled. Those photographs are highlighted in blue in the summary table.

Slide film was used for all photo points, due to the archival characteristics of slides. Elitechrome 200 ASA was the film of choice. A Nikon 6006 camera with a 28-85mm lens was used, with the automatic focus option switched on at all times to assist the non-photographers of the group. All slides were scanned into computer files, labeled, burned onto a CD and provided to the AWPF by the end of January, 2001. The process was extremely time consuming. About 30 additional photographs that depict the overall project and logistics were taken to be used for future presentations and posters.

The following photo points were selected as representative samples for this task report:

- 2nd Redbud Alcove 1 - view 1 - shows upper portion of the canyon and seeps
- Carbon 5 - view 1 - shows upper Carbon with dense tamarisk and mesquite
- Lava Chuar 4 - view 2 - shows a view from the start point of Lava Chuar #2 transect
- Lonetree 1 - view 1 - note that tamarisks grow out of rocks
- Serpentine 1 - view 1 - shows the gravelly drainage in the lower portion of the canyon
- Serpentine a - view of Serpentine 1
- Serpentine 5 - view 1 - view down Serpentine #1 transect
- Waltenberg 2 - view 1 - from the end of Waltenberg #1 transect
- Elves 1 - view 1 - view down Elves #1 transect
- Elves 4 - view 1 - see red buds grow
- Lower Blacktail b - shows tamarisk seedlings along Lower Blacktail #1 transect
- Forster 2 - from end of Forster transect #1
- Forster 3 - view 1 - shows view down canyon from a seep area
- Forster c - shows Forster 3 photopoint with Fred
- Specter b - shows Dave as the pokey-mon
- Specter 3 - view from start of Specter #2 transect
- Slimey Tick 2 - view 1 - prime example of the importance of this project
- Slimey Tick 2 - view 2 - ditto
- Cove 1 - view 1 - shows view down Cove transect #1

- Cove 1 - view 2

The photos are included as Appendix 6E - *Representative Samples of Photopoints*. Copies of all of the AWPF data sheets are not included in this report, but can be provided by the NPS upon request. The majority of the photographs turned out great and really enhanced the monitoring of this project. When used properly, qualitative monitoring can be just as powerful as quantitative monitoring. I must add that Dave C. must be extremely photogenic because he ended up in more than his share of photos.

SOUTHWESTERN WILLOW FLYCATCHER HABITAT ASSESSMENTS

Southwestern willow flycatcher surveys were conducted in 1992-1994 in Shinumu Canyon, Tapeats Canyon, Deer Creek Canyon, Havasu Canyon, Kanab Canyon, Spring Canyon, and Three Springs Canyon. No birds or breeding activity were observed in these surveys (T. Tibbitts, pers. comm.) and there are no other reports of the flycatcher's breeding in tributaries in Grand Canyon. Although the park's biologists feel that this project will have insignificant to no effect on the Southwestern willow flycatcher (SWIFL), the park has been proactive on dealing with this issue. Tim Tibbitts recommended that the park complete habitat assessments in the tributaries that eradication was proposed for. The habitat assessments had to be conducted by a certified SWIFL biologist, and the information generated from the assessments assisted the U.S. Fish and Wildlife Service and Arizona Fish and Game to make a determination about the project.

Lara Dickson, a park avi-fauna technician, initiated the habitat assessments in August of 1999. She completed assessments in about 50 tributaries, some of which are on the list of tributaries for this project. John Grahame, a certified SWIFL biologist, completed habitat assessments for the 43 remaining tributaries that are included in this project. The only areas in which habitat assessments have not been completed are Lower Bright Angel, Palisades and Honga Spring (which may be added to the list in the future).

Please refer to Appendix 6F - *Southwest Willow Flycatcher Habitat Assessment Data* for the full report. Of the 63 tributaries assessed to date, it was determined that 59 do not contain SWIFL habitat. Four of the 63 canyons (Lower Little Colorado River, Upper Carbon Creek, Three Springs Canyon and Trail Canyon) were recommended for further assessment for the following reasons:

- The Lower Little Colorado River area was assessed up to Beamer's cabin. There were scattered tamarisk, but also some dense patches with other species such as phragmites intermingled. Since it is a perennial stream, it was recommended that the area be examined by another SWIFL certified biologist. (Grand Canyon Wildlands Council understands this area is also a concern for fish resource management and thus will not be slated for tamarisk removal in the scope of this project.)
- Carbon Creek was assessed from the river to about 1km above the fault. Above the fault there is a mesquite thicket and some sections of rather dense tamarisk. There was no surface water in October during the assessment, which is one of the characteristics of good habitat. However, the patch size is 60-80m wide with a relatively dense understory, which is a characteristic of good habitat. It was recommended that the upper portion of Carbon Creek be examined by another SWIFL certified biologist.
- Three Springs was assessed briefly due to the extreme weather conditions that day; however, it appears to meet some of the criteria for SWIFL habitat. It lacks good overstory

vegetation. It was recommended that the canyon be evaluated by another SWIFL certified biologist.
- The majority of Trail Canyon is not SWIFL habitat; however, there are some larger patches with mature trees that could provide habitat. It was recommended that the patches be evaluated by another certified SWIFL biologist.

The determination of whether additional surveys or assessments were required in any of the project areas was made by the U.S. Fish and Wildlife Service under the Section 7 Biological Assessment during the NEPA process. Lara Dickson drafted the Biological Assessment. The Biological Assessment evaluates the effects this project could have on all threatened and endangered species within the park. The park kept Grand Canyon Wildlands and AWPF informed about the decisions that came out of that process.

During the habitat assessments, representative photographs were taken in each of the areas. Please refer to Appendix 6G - *Southwestern Willow Flycatcher Habitat Assessment Photo Log* for the complete list of photographs. A total of 135 photographs were taken for this portion of the project. Again, the photographs were named for each canyon and then enumerated in each area. For example, the sixth photograph taken for these purposes in Kwagunt Canyon is labeled as Kwagunt HA-6, a process that should be easy to understand. Some of the photographs taken during the initial assessments in 1999 are missing in action and may be retaken in the future if they are not located. Those canyons are listed in the log, but photographs of those 14 areas are not currently available.

A sample from the complete photograph set is included in Appendix 6H - *Representative Samples of Habitat Assessment Photographs*. The photographs included in Appendix 6H are the following:

- Pipe Creek HA-6
- Ruby Canyon HA-1
- Bighorn Wash HA-3
- Cranberry HA-2
- Matkatamiba HA-3
- Ledges Spring HA-1
- Slimey Tick HA-3
- Three Springs HA-1

As with the other photographs, all of the habitat assessment slides are scanned into computer files and burned onto CD. The complete set of photographs was submitted to Grand Canyon Wildlands and AWPF.

MAPPING

A GPS unit was used on the trip to collect accurate location data for the photo points and transects. From the GPS data, a map was created to show the overall project area. The GPS data that was used to generate the map is included as Appendix 6I - *GIS Mapping Data*. The map depicts the transect and photopoint locations, as well as the survey results for the tributaries included in this project. The areas in which habitat assessments have been conducted are also depicted on the map. Tamarisk populations were mapped and the eradication data included on the final project map. The general project location map is included in this report as Appendix 6J -

Overall Project Map. In addition to the GIS map, the hand drawn maps of the transect areas are included in Appendix 6K - *Maps of Transects*.

TRIBUTARY LIST REVISIONS

After review of the initial surveys and habitat assessments, the following changes to the original tributary list submitted to the Arizona Water Protection Fund were recommended:

Add to the List:

Palisades
Garnet Canyon
Fishtail Canyon
Honga Spring (depending on tribal approval)

Remove from the List:

Cave Spring Area
Lower Little Colorado River
Hance Spring
143 Mile Spring
Three Springs

Survey data for all of these areas are included in Appendix 6A. The additions were recommended based on the limited amount of tamarisk in those areas and the feasibility of control. Seeps and springs were noted in those areas during initial surveys, thus they would be listed as a high priority for tamarisk control actions. Cave Spring Area was suggested for removal from the list because the overall extent of the area is not yet determined and further surveys need to be completed. The Lower Little Colorado River and Three Springs were suggested for removal from the list because further Southwestern willow flycatcher assessments were recommended. Without knowledge of the outcome of those assessments, park staff felt that it was wise to remove those areas from the list. Hance Spring and 143 Mile Spring were suggested for removal from the original list because initial surveys revealed that no tamarisk were present. However, the park continues to monitor those areas. Canyons that occur on tribal lands were removed from this list later, depending on the outcome of further consultations during the Environmental Assessment process.

Conclusions

This first river trip was very beneficial to the project. Future trip logistics were discussed and evaluated, which made those trips much easier to plan. Despite the weather, 95% of the scheduled work was completed and we were more fully prepared for the eradication portion of the project. The installation of transects is time consuming and logistically challenging, and to combine the complete installation of the monitoring system with the first eradication trips would have been a mistake. Relocating the transects was relatively easy because of the photographs, GPS readings and maps. The installation of the remaining photo points was also relatively easy since eradication teams was already be in those canyons. For the most part, the monitoring plan was about 75% implemented with this trip. The assistance of park rangers (on the trip) and South Rim staff was invaluable in arranging for alternate take-out logistics.

SECTION 7: ESTABLISHMENT AND MONITORING OF A 10-ACRE STAND OF NATIVE VEGETATION AT LEES FERRY

By Fred Phillips

Introduction

Lees Ferry, located in Glen Canyon National Recreation Area, is a major recreation hub for river runners, naturalists, sports fishermen, backpackers and boaters. Lees Ferry is located at the transition between Glen and Marble Canyons, areas that support over 400 species of birds, fish, mammals, amphibians and reptiles including the endangered Southwestern willow flycatcher. By 1975 the floodplains of Lees Ferry had become completely infested with tamarisk, an exotic plant species. The invasion of tamarisk at Lees Ferry led to a decline in native cottonwoods, willows and various riparian shrubs on which native birds and other wildlife depend.

In response to the tamarisk invasion at Lees Ferry, Grand Canyon Wildlands Council and Fred Phillips Consulting obtained this funding from Arizona Water Protection Fund to restore 10-acres of tamarisk dominated riparian land to its native condition. We tested the soils and water table depths on site and generated a site revegetation plan. After this we cleared the site of tamarisk. In the summer of 2001, we started the revegetation and monitoring process. We planted approximately 950 native plants. The majority of the new plants comprised Fremont cottonwoods, four-wing saltbush and three different species of native willows but we also included netleaf hackberry seedlings as well as shrub live-oak, single leaf ash, box elder, desert olive, greasewood, apache plume and squawbush.

Below, we present data on plant species-specific survival rates and growth rates for the first and second growing seasons of the 10-acre re-vegetated area at Lees Ferry. We compare species growth and survivability to our long-term survival goals and to different EC and water table depths on the site. We also calculate species-specific foliage densities and volumes and discuss overall growth and health of plants from the planting stage until dormancy in early November. Finally, we evaluate this revegetation method in terms of its potential for establishing a long-term self-sustainable riparian habitat. This effort is a natural complement to the removal of tamarisk in the tributaries of Grand Canyon, because it provides a pilot demonstration of restoration that could be extended to specific localities (based on historic documentation) along the mainstem Colorado River in Grand Canyon, where removing tamarisk and restoring cottonwood/willow riparian forest may one day be feasible.

Methods

PRELIMINARY ANALYSIS

Preliminary soil analysis involved data collection at 14 points randomly selected throughout the 10-acre site. At each of the data points, soil samples were taken near the surface, and at depths of three, six, and nine feet using a nine-foot, 2.5-inch diameter, hand-operated auger. Samples were placed in sterile whirl-paks® and labeled for later lab analysis. Salinity or electroconductivity (EC) levels were determined by mixing distilled water and the soil in a 2:1 ratio. Samples were vigorously shaken for one minute and allowed to settle. Extracts were then analyzed in mmhos/cm using a Kelway model SST Soluble Salts Tester.

Existing vegetation at each of the sample points was noted for overall health on a 0-4 scale, zero indicating dead and four corresponding to excellent. Vegetation height was also noted using a standard measuring pole.

Six photo-monitoring points were established and panoramic pictures taken at each point with the center marked using a compass and GPS. Camera type and height, film speed, and weather conditions were also noted.

INTENSIVE SOIL SAMPLING

Intensive soil analysis involved using an EM38 electromagnetic meter (geonics limited) to collect salinity data points on a 100’x25’grid across the entire site. A total of 235 sampling points where collected. At each sampling point the conductor took salinity measurements at a 2’ and 5’ depths totaling 470 measurements. The information from the EM38 was then compared with the hard soil data collected from 14 points to ensure the accuracy of the data collected with the EM38. A Trimble XTS Pro map grade GPS survey unit was used to identify grid locations for collected data and elevation information. From this data the soil type, salinity levels, and surface-to-water-table depth were mapped. This data was mapped using Surfer® software (Golden Software Inc.) and put into a GIS/Arc View format. From these values we determined what species are suitable for the site and developed a detailed planting design for the 10 acre site delineating species to be planted, plant spacing, beaver fence location and a detailed irrigation design. The map in Appendix 7A demonstrates the location of preliminary sampling points, the intensive analysis sampling grid and Photomonitoring locations.

PLANTING DESIGN

On the basis of the site conditions summarized above we developed the revegetation planting design. This planting plan includes 270 cottonwood, 105 gooddings willow, 115 sandbar willow, 140 inkweed, 95 seepwillow, 140 fourwinged saltbush, 11 netleaf hackberry, 11 desert olive, 11 greasewood, 11 apache plume, 11 shrub live oak, 11 squawbush, 11 single leaf ash and 11 box elder. This revegetation plan totals 950 plants. A full-scale map of this design is included with the appendices at the back of this report. The design plan includes construction details on the irrigation system and planting design components of the project.

CLEARING

We cleared all tamarisk and exotic plant vegetation with a D-6 bulldozer, leaving the cleared material in windrows on site, and prepared the site for revegetation in a selective manner, saving any valuable native trees and shrubs already on the site. We coordinated all clearing activities with the GCNRA maintenance crew and rangers. The sites in sections 1 and 2 were used by boaters for camping. These were only temporary camping sites and subject to review as part of river planning.

TILLAGE

We augered holes (approximately 1000) with a backhoe or similar equipment at least 18 inches in diameter and 8’ deep (or to the water table, if shallower) where each propagule was to be planted. The existing tilled soil served as the planting medium in each augured hole.

IRRIGATION SYSTEM

We constructed an irrigation system for the ten acres of revegetation. The irrigation system consisted of a 2-3” polyethylene main (depending on available water pressure) line running along the length of the north border of the site with 1/2” polyethylene laterals running south from the main line. Each planting hole (approximately 1000) had 1- 6-gallon per hour drip emitters attached to the ½” inch laterals. We installed the irrigation system above ground. The system runs from the 6” existing water main running along the north border of the site. 2- 2” pressure-compensating valves with backflow and filter and an electric irrigation timer installed at the bathroom facility are the control devices for the irrigation system. We coordinated all construction activities with the GCNRA and GCNP maintenance crew and rangers during the construction period.

PROPAGULES

We took cuttings of local genetic stock and planted the propagules in one-gallon pots. Potting material consisted of equal portions of sandy soil from the revegetation area, and composted mulch. The propagules consisted of the following plants in the following amounts. The extra plantings (300) were used to replace dead or dying trees in the revegetation project:

Propagule Name	**Aproximate amount**
Gooddings willow (*Salix gooddingii*),	120
Coyote willow (*Salix exigua*),	170
Fremont cottonwood (*Populus fremontii*),	400
Fourwing saltbush (*Atriplex canescens*),	150
Seepwillow (*Baccharis salicifolia*),	150
Inkweed (*Suaeda torreyana*),	150
Netleaf Hackberry (*Celtis reticulata*),	20
Desert Olive (*Forestiera neomexicana*),	20
Greasewood (*Sarcobatus vermiculatus*).	20
Apache Plume (*Falugia paradoxa*)	20
Shrub live oak (*Quercus turbinella*), Liners not 1 gal	20
Squawbush (*Rhus trilobata*)	20
Single Leaf ash (*Fraxinus anomola*)	20
Box Elder (*Acer negundo*)	20
Total # of propagules	**1300**

The propagules were prepared from cuttings (when possible) and seeds from existing local genetic stock. We prepared approximately 1300 propagules for the site. This number provided approximately 300 extra plants for dead plant replacement. The propagules had an established root system and were in healthy growing condition at planting. The Fremont cottonwood and the sandbar and Goodings willow had a minimum height of 18-24” when they were planted. A final planting list with exact numbers for each species needed was submitted to Grand Canyon Wildlands upon the final planting design in December 2000, the final planting list did not drastically change from the preliminary list and the total propagules number and species used did not change. From the preliminary site investigations a majority of the plant species used were Goodings willow, sandbar willow, Fremont cottonwood, fourwing saltbush, Inkweed and seepwillow.

PLANTING

In the first week in May (or one and a half months into the growing season) the grantee planted the aforementioned plant species according to the final planting design. The grantee placed 2 slow release fertilizer tablets in each planting hole. At each planting the grantee installed 3' high, 18" diameter ring of 2" grid hog wire secured to 2-3/4" rebar posts. In areas where the individual hog wire rings were not installed we installed a 3 foot high hog wire beaver fence with ¾" rebar posts on 10' centers as specified in the final planting design to control browsing by beaver and damage to the young trees. The fence was buried at least two inches into the existing soil to prevent beavers and small rodents from establishing runs under the fence.

IRRIGATION AND WEEDING

We ensured that approximately 8 gallons of water per day was delivered to each tree through six gallon per hour pressure compensating emitters for 7 days a week until the end of the first growing season. The grantee was responsible for weekly maintenance of the irrigation system to ensure that timers and valves were operating correctly. The grantee also cleared and/or replaced any clogged/dysfunctional emitters during this weekly maintenance. The grantee weeded exotic and invasive plants and replanted dead trees as needed during the first season irrigation period. Before the second growing season the grantee replaced and repaired any damaged sections of the irrigation system and starting at the onset of the growing season irrigated the site at a rate of 8 gallons per planting/day, 7 days a week for full second growing season. The grantee also replanted dead trees with any leftover plant stock from the original 1300 propagules. The grantee also weeded the site from exotic plant species. By this point in the second growing season the plantings should have been well established for long-term self-sustainability. The NPS was willing to continue irrigation into the second and third growing seasons, ensuring that the plants were well established. GCNRA is completeing an operation and maintenance agreement with AWPF.

PLANT MONITORING

Fifteen transects were randomly selected for monitoring throughout the 10-acre re-vegetation site (See Figure 7.1). Bi-weekly monitoring sessions were conducted from the initial planting date July 7, 2001 until plants appeared to be dormant November 8, 2001. Monthly monitoring continued through the winter of 2001-2002 as well as spring and summer of 2002, to be considered as the second growing season. Monitoring sessions were conducted until November 28, 2002, when the plants appeared to be dormant. The plant growth and growth rate results are based on the data collected from both growing seasons, totaling 286 monitoring days. Each transect had one species of each of the most common species planted in the following order: Fremont cottonwood, sandbar willow, Goodding willow, four-wing saltbush and seep willow.

Plant heights to the tallest outstretched leaf were measured in each monitoring session and estimates of overall condition were recorded. A score of 0 was given to any plant that was dead; 1, for poor condition; 2, for fair condition; 3, for good condition; and 4, for excellent condition. Presence or absence of browsing by insects or mammals was noted as well as herbicide use and any other factors that could affect plant health. Notes on natural regeneration of both native and non-native plants were taken at each monitoring session. In addition, spot sampling of box elders, live oaks and single-leaf ash growth rates and conditions were taken to monitor the success of other planted species.

From plant heights, we calculated plant growth through time, foliage density and foliage volume for the five main planted species. Foliage density is actually a calculation of ground cover and is measured as an area. Foliage volumes and densities were calculated per Anderson and Ohmart. 1987. From data on plant condition and browsing presence we evaluated overall health of each species and determined survival rates. Survival rates and plant growth were then compared to the various soil conditions and water table depths on site to determine whether these conditions affected plant growth and survival for any species.

Results

SPECIES-SPECIFIC GROWTH RATES AND CONDITIONS

Fremont Cottonwood

Overall, cottonwoods did very well during the first and second growing season at Lees Ferry. Cottonwoods averaged 30 inches tall (Number (N)= 15, standard error (SE) = 2.9; Figure 7.5) at planting and sixteen months later had grown to an average of 120 inches tall (N=15, SE= 6.5; Figure 7.5). This is an average total growth per tree of 90 inches (N= 15, SE= 6.3) and an average growth rate of about .31 inches per day (N= 15, SE= .02). The total growth and growth rate results are based on the collected data for the two growing seasons combined, totaling 286 monitoring days.

Cottonwoods tended to grow fastest during the month of August 2001, one month after planting. During this time the fastest growing cottonwood that we measured grew 2.58 inches per day between August 16th and August 29th, 2001. The average growth per day for all cottonwoods sampled during this time was 1.63 inches per day (N=15, SE=0.23). Trees started to go dormant in early October and most were dormant by mid-November, 2001. Within the second growing season, cottonwoods growth rate slowed down, as their fastest rate was between June 16th and July 18th, 2002. The average growth per day for all cottonwoods sampled during this time was 0.46inches per day (N=15, SE=0.08). By the end of the season, cottonwoods average rate of growth leveled off. A possible factor for slowed rate of growth could have been the intense removal of tamarisk in the close proximity of the native plants, which involved a spray application of Garlon. This application session was conducted in early August 2002 to control invading tamarisks. As a result, the cottonwoods had dried out terminal stems and leaf burn from wind-transported Garlon. Overall, the cottonwoods were not critically affected.

The overall health of cottonwoods on the site was between excellent and good throughout our monitoring sessions (Figure 7.6). Survival rate for cottonwoods was 100%, which is within the 5-year survival goal of 80-100%. Herbivory by insects (primarily aphids and galling insects) and mammals (primarily rabbits and beavers) was minimal (Figure 7.7). Only three trees had signs of beaver browsing on the lower branches that had grown outside the protective caging.

Foliage volumes of cottonwoods averaged 4.3 ft^3 (N= 15, SE= 1.7) at planting and 205.4 ft^3 (N=15, SE= 52.0) by the end of the growing season. Foliage densities were measured as square foot ground cover. Foliage densities averaged 5.04 ft^2 (N=15, SE= 1.2) at planting and 73.6 ft^2 (N=15, SE= 14.0) by the end of the growing season. This represents a 97% increase in foliage volume and a 92% increase in foliage density (Table 7.1).

Four-Wing Saltbush

Four-wing saltbush experienced lower growth rates than cottonwoods and lower overall health than cottonwoods during the first growing season, although the growth rates dramatically increased in early summer 2002 (Figure 7.8 and 7.9). At planting four-wing saltbush averaged 8.2 inches in height (N=15, SE= 0.43) and by November 28, 2002 plants averaged 23.4 inches in height (N=15, SE= 4.4). For the 286 day monitoring session including both growing seasons, growth rates averaged 0.07 inch per day (N=15, SE= 0.02).

The height of the four-wing saltbush plants was highly variable at the end of the first monitoring season, which may have been largely due to the presence or absence of browsing by rabbits and a lesser degree by insects. Up to 80% of four-wing saltbush experienced some form of herbivory. Plants that were not browsed or lightly browsed grew an average of 30 inches between July 7th and November 8th, 2001 while plants that were heavily and continuously browsed grew about 5 inches total throughout the first monitoring season.

The decline in health of four-wing saltbush over the first growing season could be linked to the increase of browsing as well (Figure 7.9 and 7.10). Health of plants declined throughout the first season and browsing increased throughout the first season. However, while health declined it did not decline to a critical level and most plants, despite browsing, were still found to be in good condition (Figure 7.10). The declining health of four-wing saltbush during the second growing season could be linked to the application of Garlon to tamarisk weeds in close proximity to the plants, since there was a decrease in browsing and decrease in average rate of growth per day (Figure 7.10). The health declined greatly during August, September, and October 2002 as a result, although the plants increased in condition before dormancy. Despite the decline in health, all but three four-wing saltbush plants survived making the 5-year maximum goal of 80% survival. This marks above average for the 5-year goal of 60-80% survival. Foliage volumes of four-wing saltbush plants averaged 0.10 ft^3 (N=15, SE= 0.015) at planting and 7.4 ft^3 (N=15, SE= 5.2) at the end of the growing season. Foliage densities increased from 0.7 ft^2 (N=15, SE= 0.07) to 11.0 ft^2 (N=15, SE= 5.4) over the growing season. This is a 93% and 88% increase respectively (Table 7.1).

Goodding Willow

Average growth rates per day for Goodding willow, based on monitoring data for combined growing seasons, were 0.16 inches (N=15, SE=0.02). This represents an increase from 23.63 inches (SE=0.88) at planting to 68.50 inches (SE=6.06, N= 15) by the end of the second growing season (Figure 7.11). The condition of Goodding willow averaged from good to excellent and changes in condition do not appear to be directly related to herbivory (Figures 7.12 and 7.13). Survival rate of Goodding willow was 100% well within the 5-year goal of 80-100%. Goodding willows grew more than the other two willow species planted.

Foliage volumes of Goodding willow averaged 1.48 ft^3 (SE=0.15, N=15) at planting and 45.2 ft^3 (SE=20.8, N=15) at the end of the growing season. Foliage densities increased from 2.8 ft^2 (SE= 0.2, N=15) to 25.5 ft^2 (SE= 8.2, N=15) over the growing season. This is an 82% and 77% increase respectively (Table 7.1).

Sandbar Willow

The condition of sandbar willow averaged 3.9 at planting and 4 by the end of the first growing season (Figure 7.15). There was a low in condition of these plants in the second and third week of August 2001 corresponding to an increase in browsing to 6.7 % of plants being browsed. Browsing also increased near the end of the first growing season to 20% of plants being browsed but this did not seem to affect the condition of the plants as much as it did during the earlier part of the first growing season (Figure 7.16). The health declined greatly during August, September, and October 2002, which may have resulted from the application of Garlon to nearby tamarisk weeds. The plants increased in condition before dormancy. Sandbar willow was more sensitive to the Garlon overspray than any other monitored species. Despite the declination of health, all but two plants survived totaling a percentage of survival as 87%, still above the estimated 5-year survival goal of 75-80%.

Sandbar willows grew more than the other two willow species planted after the first growing season, although the average growth rate slowed down by the second season (Figure 7.14). By the end of the 2nd summer, sandbar willows averaged 73.73 inches in height (N=15, SE= 2.9), which is an increase of 39.9 inches over the average height at planting. Growth rates for sandbar willow averaged 0.14 inches per day (N=15, SE= 0.01), based on the monitoring data collected for both growing seasons, totaling 286 days.

Foliage density of sandbar willow increased by 76%, from 5.8 ft^2 (SE= 1.07, N=15) to 27.2 ft^2 (SE= 4.2, N=15) by the end of the growing season. Foliage volumes similarly increased from 0.5 ft^3 (SE= 0.065, N=15) to 45.3 ft^3 (SE= 10.1, N=15) an increase of 87%. Foliage volumes and densities of sandbar willow were higher than the other two willows as well (Table 7.1).

Seep Willow

Of all monitored species, seep willow was the most affected by insect herbivory during the first growing season. Aphids were often found in thick densities on the stems of seep willow plants and galls were prevalent. Percentages of plants with insect infestations reached a high of 93% towards the end of the first growing season (Figure 7.18 and 7.19), although low to no browsing occurred during the second growing season, which may be due to air transported Garlon. Overall seep willow had the second lowest growth rate of all species during the first and second growing seasons combined averaging 0.09 inches per day (N=15, SE= 0.01) with many plants not growing between monthly monitoring sessions. All plants were browsed or affected by insects or herbicide at some point during the monitoring seasons and one plant died as a result of rabbit browsing. However, despite these adverse affects, 93% of the seep willow plants survived the first two growing seasons, well above the estimated 5-year survival goal of 60-80%.

Seep willows grew an average of 26.32 inches (N=15, SE=4.01) between July 7, 2001 and November 28, 2002 (Figure 7.17). At the end of the growing seasons seep willows averaged 42.73 inches in height (N=15, SE= 4.12). As these plants get more established it is possible that they will develop a better resistance to browsing and then will be able to grow at levels comparable to the other willow species.

Foliage density of seep willow increased by 83% from 1.4 ft^2 (SE= 0.24, N=15) to 10.1 ft^2 (SE= 2.56, N=15) by the end of the second growing season. Foliage volumes similarly increased from 0.5 ft^3 (SE= 0.065, N=15) to 10.9 ft^3 (SE= 3.31, N=15) an increase of 91%.

AFFECT OF SOIL CONDITIONS AND WATER TABLE DEPTH

No survival rates of any species were affected by differences in EC levels or depths to the water table. We had six mortalities total throughout the monitoring session and both were probably due to mammal browsing. During the first growing season, one seep willow died from rabbit browsing and one Gooddings willow was clipped to the ground by a beaver. During the second growing season, the application of Garlon to nearby tamarisk fatally affected two four-wing saltbushes and two sandbar willows. The Gooddings willow grew back. As plants become more established (years 4-5) and develop deeper root systems we expect more mortality/stunted growth due to varied water tables and/or high soil salinities. It typically takes 4-5 years for plants on a revegetated site to show signs of being affected by unsuitable soil salinities and watertable depths.

Regression analysis showed that there was no correlation between EC level or water table depth on growth rates for any species monitored. All plant species had growth rates that were independent of soil salinities and water table depths at this time (Table 7.2). There may be several reasons for this.

It is possible that this soon after planting plant root systems are not well developed or deep enough to be affected by salinities and water table depths that we measured. In addition, throughout this monitoring session, plants were receiving supplemental surface water at the rate of 8 gallons of water per plant per day. This could alleviate the stress of a low water table for some plants and also dilute salinity levels of the soil near the surface where young root systems are concentrated.

We measured soil salinity and water table depth before grading the site so conditions may have changed slightly from our original sample readings. We corrected water table depth for changes after grading by overlaying the new topography over the original water table depth sample map. However there was no way to correct for changes in salinity levels after grading. However, we are not surprised that there is no relationship between EC, water table depth and growth rates at this time. Similar to plant survival rates, plants must be more established with deeper root systems before they are significantly affected by these factors. This typically takes 4-5 years to see changes in growth rates, mortality and overall plant health.

NATURAL REVEGETATION AND MISCELLANEOUS PLANTED SPECIES

Spot sampling of less dominant planted species showed positive growth rates and condition levels on par with the cottonwood, willow and four-wing saltbush species. The general condition of box elder, scrub oak and single-leaf ash species averaged 3.25 (N=5, SE= 0.1) at planting and 3.35 (N=5, SE=0.06) by the end of the second season. Average height of all species at planting was 20 inches (N=5, SE= 1.7). By November 28, 2002, this species had grown an average of 48.6 inches (N=5, SE= 4.5) to an average height of 65.2 inches (N=5, SE= 7.0). Browsing was minimal on all species. These plant species also showed adverse effects from the wind-transported Garlon although, despite the declination in health, the plants showed an increase in health and 100% of the spot sampled plant species survived.

There was an impressive natural colonization of native species on the cleared site. Inkweed and arrowweed came back in great numbers and all plants observed were in excellent condition and demonstrated very robust growth. Natural colonization of inkweed and arrowweed species comprised approximately 15% of the site area.

Tamarisk came back at varying frequencies throughout the site. On the lower terrace areas regeneration of tamarisk was minimal. However, areas on the higher terrace experienced a surprisingly high frequency of tamarisk regeneration. The difference in tamarisk regeneration is probably related to the amount of soil taken off the top of the site during grading. In the lower terraces of the site 18 inches or more soil was removed however, on the higher terrace we were not able to take off a full 18 inches of soil. Because of budget and permitting constraints we could not remove soil from the site and windrows would have been exceedingly high with more topsoil removal on the upper terraces. In previous re-vegetation efforts the removal of at least 18-30 inches of soil from the surface has been adequate for stopping root/stem material tamarisk regeneration and less than 18 inches has required intensive hand removal of regenerating tamarisk and the use of Garlon, a herbicide control. To stop the tamarisk regeneration on the higher terrace Richard Clark and Flagstaff Native Plant and Seed regularly pulled tamarisk on site and applied Garlon to cut stump tamarisk when necessary.

In addition to regeneration of tamarisk and colonization of native plants, there were at least 3 other non-native species of plants observed on site, including: Russian thistle, Common Purslane, and Maize. However, all of these species were seen in very low numbers.

Conclusions

Overall, all native plant species planted survived the first two growing seasons in excellent condition and appear to be adequately suited to the Lees Ferry riparian environment. All plant species fell within or above our estimates of survival over a five-year period. Growth rates, resistance to browsing and overall health were strong for all species indicating that plants are well on the way to establishing themselves in the re-vegetation area. In addition, there was a high re-colonization of native plants in the absence of tamarisk. This indicates that the natural potential for re-colonization is high as soon as competition from tamarisk is removed. We expect to see continued colonization of native plants throughout the restoration process.

At this time soil salinity and water table depth do not affect the survival or growth of any planted species. However, we expect to see effects of soil salinity and water table depths as plants become more established on the site. This could take up to 5 years. More immediate threats to survival and growth of plants are browsing by mammals and insects. Browsing by insects tended to be higher in cooler times of year and lower in the warmest parts of the summer. Plants tended to grow fastest during the warmest months of the summer, especially cottonwoods. This is probably due to the combination of decreased insect herbivory and the increased hours of sunlight.

Besides browsing and slight affects from incompatible soil salinities and water table depths, other threats to the establishment of a thriving native riparian community are exotic species and human recreational activities. In the lower terraces of the site exotic species are minimal and do not pose a threat. On the higher terrace tamarisk and a few other exotic species exist in higher frequencies. These species should be pulled as often as possible. Because Lees Ferry is a major recreation facility, potential for human impacts on the site are high. Posted signs that inform people of this sensitive and regenerating area should be kept clearly visible.

The dramatic increase in foliage densities and volumes of plants from planting to the end of the monitoring season suggest that this area is well on its way to becoming suitable riparian habitat that will be increasingly used by insects, birds, reptiles and mammals. Foliage density in riparian habitats is often used as one of several predicting variables for assessing quality of habitat for wildlife (Anderson and Ohmart 1987). Lizards, as well as some rodents and birds, have been shown to increase on sites as foliage density increases (Anderson and Ohmart 1987). We have already noticed what appears to be an increase in numbers of whiptail lizards on the site, however this was not formally quantified. On-site avian censusing showed that despite initial low avian abundance following vegetation clearing, birds slowly started to use the area again. We expect to see a more dramatic increase as trees and shrubs continue to grow over the next growing season. As trees and shrubs grow in height, foliage densities increase two-fold and foliage volume increases cubically so even small changes in plant height can result in a dramatic increase in foliage cover. Thus, we expect that as plants continue to grow over subsequent years, vertebrate animals will respond positively to the return and growth of these native riparian species.

Prognosis for the Future

As the revegetated plants continue to grow over subsequent years at the Lees Ferry site, the cottonwood/ willow forest along the lower terrace of the site should grow into a mature, healthy stand of quality riparian habitat. Along the upper terrace, a healthy stand of seep willow, four-wing saltbush, arrowweed and inkweed should continue to naturally recolonize. Cottonwood and willow plantings on the upper terrace will continue to grow, but because of the 8-15' deep water table they may not mature as quickly as the lower terrace plantings. In years 3-5 we should also begin to see the effects of depth to water table and salinity levels on the plantings. Exotic plant invasion by tamarisk will continue to be problematic on the site. A long-term weed management program should be implemented to prevent the reinvasion of tamarisk on the site.

A third growing season of irrigation for the native plantings was also recommended and implemented for the revegetation site. Giving the plantings a third year of supplemental water will add to the long-term success of these plantings. This report concludes the monitoring obligations of the AWPF contract. We recommend that a less frequent long-term monitoring program be established for this project. This monitoring will help determine the long-term effects of salinity and depth to water table on the establishment of native riparian plant species.

The Lees Ferry revegetation project is the result of over 4 years of planning, design, implementation and monitoring by the AWPF, GCNRA and Grand Canyon Wildlands Council. With continued maintenance and management this site will provide quality native riparian habitat for generations to come.

References

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SECTION 8: POST REVEGETATION AVIAN CENSUS

By Larry Stevens

Introduction

Grand Canyon Wildlands Council was funded by the AWPF to conduct a 4 ha pilot restoration/revegetation project at Lees Ferry, Arizona. A dense stand of non-native tamarisk (*Tamarix pentandra*) at the treated Lees Ferry (LF) site was removed and replaced with native Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingi*) and other native riparian phreatophytic plant species. Birds are excellent, conspicuous and well-known indicators of habitat quality, and assemblage dynamics change markedly in response to vegetation and environmental changes in this region (Brown et al. 1987, Stevens et al. 1997). Therefore, we monitored avifauna on the treated site and a nearby reference site (Paria Beach, PB) and this section documents the results of that avian monitoring effort. We compare avian species richness and abundance between the two study sites over a three-year interval, including one year of pre-treatment, and the first and second years of treatment. We report rapid avian assemblage recovery, attaining levels of diversity and abundance near pre-treatment levels in the second growing season.

Historical Data

METHODS

Data over the past decade have been collected on bird distribution at these two study sites. Historical data were obtained from the Grand Canyon Monitoring and Research Center, the Glen Canyon National Recreation Area (J. Spence), and L.E. Stevens' personal data archives. Data were compiled and are analyzed below.

RESULTS

The avian composition of the 2 study sites was examined through analysis of the historical data. A total of 116 bird species were detected in the Lees Ferry are from January 1994 to June 1999 (J. Spence, Ecologist, Glen Canyon National Recreation Area, Page, AZ) and Stevens et al. (1997). The Glen Canyon National Recreation Area data revealed that an average of 10.5 bird species (1 sd = 4.07 species) were detected per survey in the overall Lees Ferry area, with a mean bird species detection rate of 13.7 (sd = 7.09) birds/hr for 177 surveys. This same database revealed that, on average, 36.3 (sd = 34.2) birds were observed/survey, with a mean bird detection rate of 45.9 (sd = 37.8) birds detected/hr.

Stevens et al. (1997) examined waterbird distribution, and included a study site at Lees Ferry. They reported that impoundment impacts override natural, reach-based channel geomorpholgy influences on seasonal waterbird distribution in the Grand Canyon along the Colorado River downstream from Glen Canyon Dam. Interviews with pre-dam observers and historic literature indicate that winter waterbird concentrations did not occur prior to completion of Glen Canyon Dam (1963), and that pre-dam summer breeding was rare. River corridor surveys from 1973 through 1994 detected 25 species of diving and dabbling waterfowl, and 33 other wading, shorebird and water-associated raptor species, with a grand mean of 678.7 waterbirds/trip. The post-dam assemblage was dominated by Anseriformes (13 diving and 12 dabbling species). Winter bald eagle (*Haliaeetus leucocephalus*) concentrations and summer breeding mallard (*Anas platyrhynchos*) populations occurred, but wading birds and shorebirds occurred primarily as migrants or summer vagrants. Winter waterfowl area-adjusted rate of encounter (AARE) decreased downstream by 3 orders of magnitude from the clearwater Glen Canyon reach to the usually turbid middle and lower Grand Canyon reaches. Summer waterfowl AARE were equivalent in wide and narrow reaches upstream from the Little Colorado River (LCR), but decreased abruptly downstream. Waterfowl densities were greatest in the highly productive clearwater and variably turbid segments upstream from the Little Colorado River, but were negatively correlated with reach width. These influences resulted in a non-linear (circuitous) alteration in the assemblage over distance downstream from the dam. In addition, Brown et al. (1998) reported that human disturbance from boats and activity reduced wintering bald eagle presence in the study area around Lees Ferry.

Avian Monitoring, 2000-2002

METHODS

Study Sites

The treated stand at Lees Ferry includes approximately 4 ha of tamarisk, with some arrowweed (*Pluchea sericea*) and Russian olive (*Eleagnus angustifolia)* habitat, and a few other scattered native woody shrubs. The LF site midpoint is at N 36^{o} 51.926’, W 111^{o} 35.430’, at an elevation of approximately 952 m. The control site at PB Beach is located 1.5 km downstream from LF at Colorado River Mile 1.0R, and includes about 3 ha of dense tamarisk habitat with marginal coyote willow (*Salix exigua*), arrowweed, and Russian olive (*Eleagnus angustifolia).* The PB site midpoint is at N 36^{o} 51.325’, W 111^{o} 36.335’, at an elevation of approximately 948 m. Photographs are provided in Phillips Consulting Appendix.

Field Techniques

Avian monitoring transects were established in May 2000, with one approximately 200 m in length on each of the two study sites (Table 8.1). The sites were monitored during 12 paired sites visits from July 2000 to early February 2001 (the pre-treatment period). Also, several unpaired surveys were conducted on 31 May and 8 August 2000 on the LF site only, and 11 October on the PB Beach stand only. In all, a total of 23 individual pre-treatment surveys were conducted in the pre-treatment phase. Following tamarisk removal from the site, we continued to conduct paired surveys on the two sites. A total of 13 pairs of surveys were conducted from late February 2001 through December 2001 during the first year of treatment. We conducted a total of 17 pairs of surveys from March through December 2002.

On each survey, we measured avian abundance, detection rate, species richness, and species detection rate on the treated LF site and the nearby PB reference site. Generally, 1-3 site visits were made per month to each site over the project duration. Site visits were conducted during the morning hours, relatively early during the breeding season, and later in the cooler winter months. All birds detected on the sites were counted during a walking survey of the site, and site conditions, temperature, weather, and survey duration were recorded.

Table 8.1: Lees Ferry avian monitoring surveys, 2000-2002

Lees Ferry Surveys		**Paria Beach Surveys**	
Date	**No. Hrs**	**Date**	**No. Hrs**
5/31/00	0.67	---	---
7/16/00	1.42	7/16/00	0.58
7/30/00	0.83	7/30/00	0.42
8/2/00	0.75	8/2/00	0.50
8/8/00	0.92	---	---
8/18/00	0.50	8/18/00	0.67
9/6/00	1.08	9/6/00	1.00
9/30/00	1.08	9/30/00	0.67
---	---	10/11/00	0.67
10/24/00	1.00	10/24/00	0.67
11/18/00	0.58	11/18/00	0.42
11/30/00	0.83	11/30/00	0.50
12/17/00	1.17	12/17/00	0.58
1/4/01	1.50	1/4/01	0.58
2/4/01	0.83	2/4/01	0.83
2/16/01	0.92	2/16/01	0.67
3/6/01	0.83	3/6/01	0.50
4/13/01	0.83	4/13/01	0.83
4/26/01	0.83	4/26/01	1.25
5/3/01	1.00	5/3/01	1.08
5/19/01	0.83	5/19/01	1.17
5/28/01	1.67	5/28/01	0.83
6/9/01	0.67	6/9/01	0.75
6/19/01	0.58	6/19/01	0.58
6/29/01	0.33	6/29/01	0.42
7/26/01	0.75	7/26/01	0.83
8/26/01	0.83	8/26/01	0.67
10/29/01	0.92	10/29/01	0.75
3/10/02	0.87	3/10/02	0.67
3/24/02	0.75	3/23/02	0.75
4/7/02	1.18	4/7/02	1.12
4/28/02	1.00	4/28/02	1.00
5/5/02	0.75	5/5/02	0.75
5/23/02	0.83	5/23/02	0.67
5/31/02	0.92	5/31/02	0.58
6/11/02	0.75	6/11/02	0.67
6/26/02	1.00	6/26/02	0.58
7/26/02	0.75	7/26/02	0.75
8/21/02	0.83	8/21/02	1.00
9/13/02	0.83	9/13/02	0.58
9/30/02	1.17	9/30/02	0.77
10/11/02	0.67	10/11/02	0.58
11/19/02	1.08	11/19/02	0.75
12/30/02	0.75	12/30/02	0.75

Statistical Analyses

Analysis for this task included paired comparisons of control and treatment plot avian abundance and diversity data. The number of birds seen on the plot and the number of bird species were converted to detection rate data by standardizing against the number of hours of observation. In addition to annual and overall statistical characterization of avian species richness and abundance detection rates, the paired plot data were analyzed using the non-parametric tests to determine whether consistent differences exist between the control and treated sites. Significance criteria were adjusted in these analyses using the serial Bonferroni approach (Rice 1989) because multiple pair-wise tests were conducted on a single data set.

RESULTS AND DISCUSSION

A total of 1600 birds among at least 90 species were detected on the two study sites during the 43 project surveys in 2000-2002 (Table 8.2). The breeding bird assemblage was generally dominated by ash-throated flycatcher, Bewick's wren, blue-gray gnatcatcher, Lucy's warbler, blue grosbeak, and house finch, with 0-2 pairs of each species on each site, and regular visitation and overhead foraging by violet-green and northern rough-winged swallows. The winter assemblage was strongly dominated by white-crowned and other sparrow species, ruby-crowned kinglet, and dark-eyed junco. Both sites were commonly visited by raptors (hawks and owls) and common raven.

Table 8.2: Bird species detected in the vicinity of Lees Ferry, Arizona, and mean annual detection rate/hr at each site during the 2000-2002 project period.

Common Name	Scientific Name	2000 LF	2000 PB	2001 LF	2001 PB	2002 LF	2002 PB
Pied-billed Grebe	*Podilymbus podiceps*	0.000	0.000	0.000	0.000	0.000	0.000
Grebe sp.		0.076	0.000	0.000	0.000	0.000	0.000
American Coot	*Fulica americana*	0.304	0.000	0.000	0.000	0.000	0.000
Mallard	*Anas platyrhynchos*	1.670	0.000	2.545	0.000	0.000	0.000
Gadwall	*Anas strepera*	3.113	0.000	0.000	0.000	0.000	0.000
American Wigeon	*Anas americana*	3.721	0.000	0.000	0.000	0.000	0.000
Northern Pintail	*Anas acuta*	0.456	0.000	0.000	0.000	0.000	0.000
Lesser Scaup	*Aythaya affinis*	0.000	0.000	0.000	0.000	0.000	0.000
Redhead	*Aythaya americana*	0.000	0.000	0.000	0.000	0.000	0.000
Unknown Dabbler		0.000	0.000	0.000	0.000	0.000	0.000
Bufflehead	*Bucephala albeola*	1.215	0.000	0.000	0.000	0.000	0.000
Great Blue Heron	*Ardea herodias*	0.228	0.124	0.273	0.000	0.000	0.000
Snowy Egret	*Egreta thula*	0.000	0.000	0.000	0.000	0.000	0.000
Bl-crowned Nightheron	*Nycticorax nycticorax*	0.000	0.000	0.091	0.000	0.000	0.000
Common Snipe	*Gallinago gallinago*	0.076	0.000	0.000	0.000	0.000	0.000
Spotted Sandpiper	*Actitis macularia*	0.000	0.124	0.000	0.000	0.000	0.000
Killdeer	*Charadrius vociferus*	0.000	0.000	0.091	0.097	0.000	0.000
Longbilled Dowitcher	*Limnodromus scolopaceus*	0.000	0.000	0.000	0.000	0.000	0.084
Red-tailed Hawk	*Buteo jamaicensis*	0.000	0.000	0.000	0.000	0.000	0.000
Northern Harrier	*Circus cyaneus*	0.076	0.000	0.000	0.000	0.000	0.000
Osprey	*Pandion haliaetus*	0.000	0.000	0.000	0.000	0.000	0.000

Sharp-shinned Hawk	*Accipiter striatus*	0.000	0.248	0.000	0.000	0.071	0.000
Coopers Hawk	*Accipiter cooperi*	0.076	0.000	0.000	0.000	0.071	0.000
Peregrin Falcon	*Falco peregrinus*	0.000	0.000	0.000	0.000	0.000	0.000
Northern Saw-whet Owl	*Aegolius acadicus*	0.000	0.000	0.091	0.000	0.000	0.000
Great Horned Owl	*Bubo virginianus*	0.000	0.000	0.000	0.097	0.000	0.000
Belted Kingfisher	*Ceryle alcyon*	0.076	0.000	0.091	0.000	0.071	0.000
Mourning Dove	*Zenaida macroura*	0.076	1.114	0.273	0.387	0.283	0.167
Northern Flicker	*Colaptes cafer*	0.456	0.371	0.000	0.000	0.000	0.000
Red-naped Sapsucker	*Sphyrapicus nuchalis*	0.000	0.124	0.000	0.000	0.000	0.000
Roadrunner	*Geococcyx californianus*	0.000	0.000	0.000	0.000	0.071	0.000
BC Hummingbird	*Archilochus alexandri*	0.000	0.000	0.091	0.968	0.071	0.418
Hummingbird sp.		0.000	0.000	0.000	0.000	0.071	0.000
White-throated Swift	*Aeronautes saxatilis*	0.000	0.000	0.000	0.000	0.000	0.000
Ash-throated Flycatcher	*Myiarchus cinerascens*	0.607	0.371	0.273	0.968	0.920	0.752
Western Kingbird	*Tyrannus vociferus*	0.000	0.000	0.000	0.000	0.425	0.000
Say's Phoebe	*Sayornis sayi*	0.000	0.124	0.182	0.000	0.637	0.251
Black Phoebe	*Sayornis nigricans*	0.076	0.248	0.000	0.097	0.000	0.084
Cordilleran? Flycatcher	*Empidonax occidentalis*	0.000	0.248	0.000	0.000	0.000	0.000
Willow Flycatcher	*Empidonax traillii*	0.152	0.000	0.000	0.000	0.283	0.251
Western wood Pewee	*Contopus sordidulus*	0.000	0.000	0.000	0.000	0.000	0.167
Horned Lark	*Eremophila alpestris*	0.000	0.000	0.000	0.000	0.000	0.084
Violet-green Swallow	*Tachycineta thalissina*	0.532	0.371	0.000	0.581	0.000	3.425
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	0.228	0.619	0.000	0.194	0.071	0.251
Cliff Swallow	*Petrohelidon pyrrhonota*	0.000	0.000	0.000	0.000	0.000	0.000
Tree Swallow	*Tachycineta bicolor*	0.000	0.000	0.000	0.000	0.000	0.000
Common Raven	*Corvus corax*	0.456	0.248	0.273	0.000	0.425	0.251
Western Scrub Jay	*Aphelocoma californica*	0.000	0.000	0.000	0.000	0.071	0.000
Pinyon Jay	*Gymnorhinus cyanocephalus*	0.000	0.000	0.000	0.000	0.071	0.000
Loggerhead Shrike	*Lanius ludovicinaus*	0.228	0.000	0.000	0.000	0.000	0.000
Bushtit	*Psaltriparus minimus*	4.860	1.485	0.727	0.387	0.000	1.170
Bewick's Wren	*Thryomanes bewickii*	1.595	0.990	0.000	1.162	0.212	0.585
Canyon Wren	*Catherpes mexicanus*	0.607	0.371	0.000	0.194	0.000	0.084
Rock Wren	*Salpinctes obsoletus*	0.000	0.000	0.000	0.000	0.000	0.000
Marsh Wren	*Cistothorus palustris*	0.380	0.000	0.818	0.000	0.071	0.000
Ruby-crowned Kinglet	*Regulus calendula*	1.215	0.866	0.000	0.387	0.000	0.752
Golden-crowned Kinglet	*Regulus satrapa*	0.228	0.000	0.000	0.000	0.000	0.000
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.456	0.124	0.091	0.387	0.425	1.086
Mountain Chickadee	*Poecile gambeli*	0.000	0.124	0.000	0.000	0.000	0.000
Plumeous vireo	*Vireo plumbeus*	0.000	0.000	0.000	0.000	0.071	0.000
Vireo sp.		0.076	0.000	0.000	0.000	0.071	0.000
Lucy's Warbler	*Vermivora luciae*	0.152	0.000	0.000	1.646	0.142	0.835
Yellow Warbler	*Dendroica petechia*	0.228	0.248	0.000	1.258	0.566	0.752
Yellow-rumped Warbler	*Dendroica coronata*	0.228	0.495	0.000	0.000	0.142	0.084
Nashville Warbler	*Vermivora ruficapilla*	0.000	0.000	0.000	0.000	0.000	0.167
Common Yellowthroat	*Geothlypis trichas*	0.000	0.000	0.182	0.000	0.071	0.000
Yellow-breasted Chat	*Icteria virens*	0.076	0.000	0.000	0.000	0.000	0.000
Warbler sp.		1.215	0.248	0.000	0.000	0.283	0.000

American Robin	*Turdus migratorius*	0.000	0.000	0.000	0.000	0.071	0.000
Western Bluebird	*Sialia mexicana*	0.000	0.000	0.000	0.000	0.071	0.000
Northern Mockingbird	*Mimus polyglottos*	0.000	0.000	0.000	0.000	0.071	0.000
Brown-headed Cowbird	*Molothrus ater*	0.380	0.000	1.364	1.258	0.212	0.000
Red-winged Blackbird	*Agelaius phoeniceus*	0.228	0.000	0.000	0.000	0.354	0.000
Northern Oriole	*Icterus bullocki*	0.076	0.124	0.091	0.000	0.212	0.000
Hooded Oriole	*Icterus cucullatus*	0.000	0.000	0.000	0.000	0.000	0.000
Great-tailed Grackle	*Quiscalus mexicanus*	0.076	0.000	1.182	1.065	0.283	0.000
Yellow-headed Blackbird	*X. xanthocephalus*	0.000	0.000	0.091	0.000	0.000	0.000
Western Tanager	*Piranga ludoviciana*	0.000	0.248	0.000	0.194	0.071	0.167
Blue Grosbeak	*Guiraca caerulea*	0.456	0.124	0.182	0.774	0.071	0.418
Black-headed Grosbeak	*Pheuticus melanocephalus*	0.000	0.124	0.000	0.000	0.071	0.334
Lazuli Bunting	*Passerina amoena*	0.000	0.619	0.000	0.484	0.283	0.084
Bunting sp.		0.228	0.495	0.000	0.097	0.142	0.251
Indigo Bunting	*Passerina cyanea*	0.000	0.000	0.000	0.000	0.212	0.000
Lesser Goldfinch	*Carduelis psaltria*	0.607	0.000	0.273	0.000	0.212	0.167
House Finch	*Carpodacus mexicanus*	1.974	1.114	0.000	0.774	0.637	0.835
Dark-eyed Junco	*Junco hyemalis*	0.228	4.084	0.000	0.581	0.000	0.334
White-crowned Sparrow	*Zonotrichia leucophrys*	6.074	3.342	4.545	0.678	5.591	2.339
Vesper Sparrow	*Pooecetes gramineus*	2.809	3.465	0.091	0.387	2.052	1.671
Lark Sparrow	*Chondestes grammacus*	2.050	0.495	0.091	0.000	0.354	0.251
Black-throated Sparrow	*Amphispiza bilineata*	0.000	0.000	0.000	0.000	0.000	0.251
Lincoln Sparrow	*Melospiza lincolnii*	4.252	0.371	0.273	0.000	0.849	0.084
Chipping Sparrow	*Spizella passerina*	0.000	0.000	0.000	0.000	0.142	0.084
Unknown Sparrow		0.456	0.248	0.000	1.258	0.071	0.335
Unknown Passerine		0.152	0.000	0.000	0.194	0.000	0.000

The LF site bird assemblage changed dramatically as a result of treatment (Tables 8.2, 8.3; Figs. 8.1, 8.2). A total of 50 species were detected among 14 surveys of the LF site in 2000 prior to treatment (mean species detection rate = 10.6 species/hr), and total abundance was 596 individuals (mean abundance detection rate = 48.1 birds/hr). Removal of nearly all vegetation from the LF site in 2001 reduced the total species detected by 50% to 25 species (mean species detection rate = 3.6 species/hr), and decreased total abundance to 157 individuals (mean abundance detection rate = 13.6 birds/hr) among 13 surveys. However, rapid growth of planted vegetation on the LF site in 2002 increased total species detected to 47, and the total abundance to 250 birds, with an average LF bird species richness detection rate of 7.3 species/hr, and increased mean abundance/hr to 17.9 birds/hr, among 17 surveys.

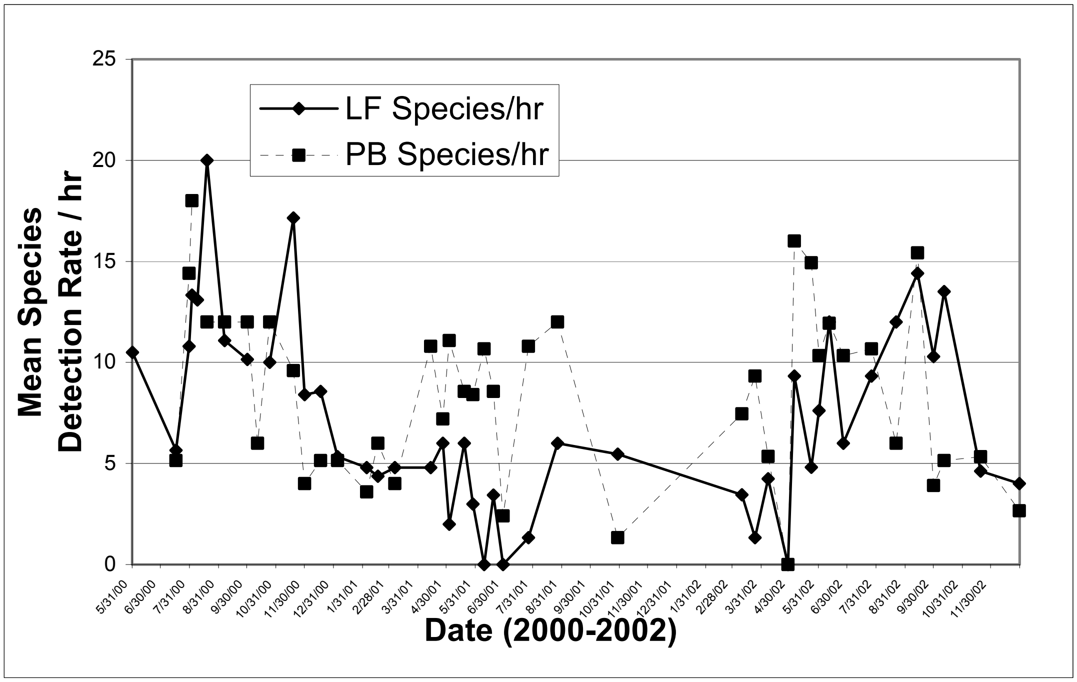

Figure 8.1: Mean avian species detection rate/hr on the LF and PB sites, 2000-2002.

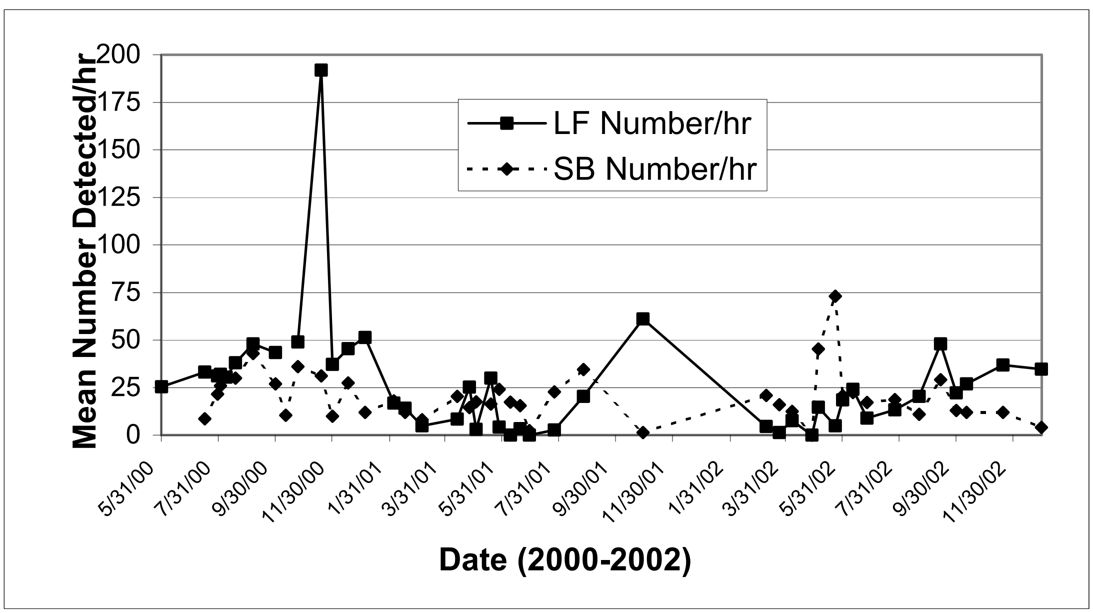

Figure 8.2: Mean avian abundance detection rate/hr on the LF and PB sites, 2000-2002.

Table 8.3: Summary of total avian species and abundance, and total species and abundance detection rate/hr for the LF (treated) and PB (control) sites, in 2000-2002.

Variable	**LF n = 14**	**PB 13**	**LF 13**	**PB 13**	**LF 17**	**PB 17**
Total No. Species Detected	50	35	25	27	47	37
Total Abundance Detected	596	195	157	171	250	231
Mean Species Detection Rate/survey	10.6	9.2	3.6	7.8	7.3	8.4
1 sd Species Detection Rate	4.30	4.60	2.20	3.48	4.39	4.73
Mean Abundance Detection Rate/survey	48.1	23.2	13.6	15.9	17.9	20.5
1 sd Abundance Detection Rate	42.55	10.84	17.33	8.94	13.79	17.41

The PB site bird assemblage changed between years, possibly in response to great variability in climate conditions (both 2000 and 2002 were drought years; (Table 8.3; Figs. 8.1, 8.2). A total of 35 species were detected among 13 surveys of the PB site in 2000 (mean species detection rate = 9.2 species/hr), and total abundance was 195 individuals (mean abundance detection rate = 23.2 birds/hr). In 2001, the total species detected decreased by nearly 25% to 27 species (mean species detection rate = 7.8 species/hr), and total abundance decreased slightly to 171 individuals (mean abundance detection rate = 15.9 birds/hr) among 13 surveys. In 2002, total species detected exceeded year 2000 levels, rising to 37 (mean species detection rate = 8.4 species/hr), and the total abundance rose to 231 birds, with an average PB abundance detection rate of 20.5 birds/hr.

Statistical comparison of data between the two sites indicated that the pre-treatment LF site (4 ha) supported significantly higher unadjusted species richness and abundance than did the PB site (Wilcoxon t= 1.5, Z = 2.488, n = 9 pairs, p = 0.0129). This was the only statistically significant variable among the abundance and diversity and detection rate variables examined using the serial Bonferroni adjustment of significance criteria for multiple tests from a single data set. This relationship was at least probably due to species-area relationships, as the differences in the rate of species richness and abundance detection were proportional to the area of the two study sites. Also, the PB tamarisk vegetation patch rather isolated, whereas the LF stand is more connected to upstream and downstream tamarisk stands. Despite differences in site structure, the two sites had fairly comparable levels of avian occupation and composition.

Following treatment, the two sites had remarkably similar total avian species richness and abundance, although the PB site had higher species and abundance detection rates (Table 8.3). Avian species richness and abundance recovered to levels near the pre-treatment level by the end of the second year of growth: the LF site avian species richness and abundance detection rates increased to within 6% of the pre-treatment levels in the second year of treatment. This rapid response was due, in part, to the rapid growth of planted trees on the LF site, and the recovery of shrub and low canopy cover. We expect that these LF bird assemblage variables will exceed pre-treatment levels in 2003.

Assemblage composition changed following treatment of the LF site, as demonstrated by detection in 2002 of roadrunner, western kingbird, northern mockingbird, and other species not detected in the pre-treatment assemblage. We expect assemblage composition to continue to change as the habitat structure matures at this site over the next two decades.

Conclusions And Management Recommendations

Our results demonstrate that the impacts of small-scale riparian habitat restoration on avian community characteristics appear to be relatively brief, with nearly full recovery of diversity and abundance and with some evidence of improvement within 2 growing seasons. Therefore, we recommend that the NPS continue to conduct small-scale, site-specific riparian habitat restoration. We further recommend that the National Park Service continue avian monitoring of avian diversity, abundance and composition on the LF stand over the next decade at a lower level of intensity. Such monitoring should indicate how increased canopy structural complexity changes the trajectory and rate of avian assemblage responses. We further recommend continued, but lower-intensity monitoring of the PB site as a reference stand. For this reason, we do not recommend restoration of the PB site, as it serves as a useful control site.

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SECTION 9: TAMARISK ERADICATION AND POST TAMARISK ERADICATION MONITORING ALONG THE COLORADO RIVER TRIBUTARIES

By Lori Makarick and Heidi Kloeppel

Overview

The work identified in the NPS cooperative agreement with Grand Canyon Wildlands Council entitled "Tamarisk Eradication and Restoration of 63 Tributaries, AWPF Contract #99-075WPF" within Grand Canyon National Park (GRCA) is completed and the National Park Service (NPS) accepts the responsibility for follow-up maintenance and monitoring. GRCA and Grand Canyon Wildlands, partnered to successfully fulfill the terms of the grant agreement. To date, three previous reports for this task have been submitted (fall 2000, fall 2002, and fall 2003), along with additional progress reports and memos. Here we summarize the work completed and reconfirm the commitments by the NPS and Grand Canyon Wildlands to the protection of biodiversity.

The primary objective of this portion of the overall project was to remove tamarisk from 63 tributaries of the Colorado River in Grand Canyon National Park. This effort has significantly reduced tamarisk distribution within the treated areas, and allowed native vegetation to reestablish in the absense of exotic plants. Prior to initiation of the project, extensive public scoping was completed and an Environmental Assessment/Assessment of Effect (EA/AEF) was prepared. Under the new Director's Orders on Compliance (NPS 2001a), cumulative effects of multiple projects were considered, and tamarisk removal in all of the park's tributaries was included in the document and analyzed. The documentation aims to ensure the use of interdisciplinary approaches and principles to decision-making, and that all decisions are based on technical and scientific information.

Public scoping and interdisciplinary team discussions about tamarisk management began in 1998. The park received a written response to the Informal Consultation with the U.S. Fish and Wildlife Service (USFWS) on January 25, 2001 and that letter, along with the incorporation of their recommended changes, completed the Section 7 consultation that was necessary for this project. The NPS issued the final Environmental Assessment / Assessment of Effect (EA/AEF) for the project to the public in February 2002. After review of the public comments, GCNP issued a Finding of No Significant Impact (FONSI) for the project in June 2002. On April 8, 2002, the State Historic Preservation Officer (SHPO) provided the park with written concurrence on the project moving forward.

After the environmental compliance (NPS 2002) and permitting process was completed, project leaders revised the Tamarisk Eradication Plan and Final Tributary List to incorporate the new project timeline, as follows:

- October 2000 – 18-day river trip, project monitoring installation
- October 2002 – 18-day river trip, tamarisk eradication trip #1
- November 2002 – 18-day river trip, tamarisk eradication trip #2
- October 2003 – 18-day river trip, tamarisk eradication trip #3
- November 2003 – 18-day river trip, tamarisk eradication trip #4, and post-project monitoring and follow-up maintenance
- May 2004 – 18-day river trip, post-project monitoring and follow-up maintenance

Project leaders and crew members conducted the first two tamarisk control trips in the fall of 2002 and the second two management trips in the fall of 2003. GRCA staff, supported by supplemental funds, completed 3 additional tamarisk management trips to complete follow-up treatment work and initiate this work in other project locations. In the period from October 2002 to May 2004, crews have removed 70,616 tamarisk trees in 70 project areas.

NPS sought and received additional assistance for this portion of the project. GRCA staff, along with the NPS Exotic Plant Management Team (EPMT) based in Lake Mead National Recreation Area, completed one additional tamarisk management trip in March of 2003. Colorado River Fund monies supported the trip, and participants completed follow-up work in 14 of the 63 areas included in this AWPF funded project. During September 2003 volunteers manually re-treated eight of the tributaries included in this project; the National Park Service's Cooperative Conservation Initiative funded that work. In March of 2004, the NPS's Colorado Plateau EPMT, the Colorado River Fund, and the Grand Canyon National Park Foundation (GCNPF) supported an 18-day river trip to assist with project work and initiate work in Phase II project locations (beyond the 63 tribuatries).

Throughout this project the public and volunteers remained enthusiastic and supportive. At this time, the NPS and GCNPF have obtained additional AWPF funding to extend this project into Phase II with eradication in 35 new tributaries, and other funding to continue the required maintenance and monitoring of the 63 tributaries. In addition to acquiring funding to support three trips during the period of this contract, the NPS received over $115,000 to continue this valuable project and essential restoration work between September 2004 and March 2005.

Area of Interest

A general description of the overall project areas illustrates the importance of protecting and restoring these project areas. High species diversity, high species density, and high productivity generally characterize riparian areas. Continuous interactions occur among riparian, aquatic, and upland terrestrial ecosystems through exchanges of energy, nutrients, and species. Warren et al. (1982) provided the following description:

> "Riparian woodlands (or forests) characterized by cottonwood-willow associations are primarily restricted to the larger perennial streams and drainages of the Colorado Plateau region of northern Arizona. The great biological importance and floristic diversity of these cottonwood-willow riparian forests is disproportionate to their limited total area…. Riparian scrub usually occurs along ephemeral or intermittent watercourses (such as desert arroyos), or in narrow canyons which are periodically scoured by floods. Riparian scrub communities are characterized by a broad continuum of vegetative associations that range from mesic vegetation types to xeric growth along desert arroyos (Brown et al., 1980). These arroyos often contain water only one day or less each year and the resulting vegetation is commonly composed of a mixture of facultative riparian species and upland species. This is in contrast to mesic species, which are generally absent from the surrounding uplands…. Side canyons throughout the park with perennial water support riparian vegetation characterized by cottonwood (*Populus fremontii*) and willow (*Salix* spp.) which is generally very similar to that found in similar situations throughout northern Arizona (Phillips and Phillips, 1979)…."

Each dry wash, spring, seep, or stream has a different association of species, depending on environmental features including elevation, permanence of water, substrate, frequency of flooding, and colonization (Warren et al., 1982). Riparian vegetation typically occurs in small, discrete stands or patches. The floristic diversity in wetland and riparian composition is highly variable, but is extremely high when compared to the upland vegetation. Typical stands may consist of broad-leaved deciduous trees in the overstory, with a mixture of shrubs and grasses in the understory. Species typical of drainages with perennial water sources are:

- ♣ Brickellia (*Brickellia longifolia*)
- ♣ Catclaw acacia (*Acacia gregii*)
- ♣ Apache plume (*Fallugia paradoxa*)
- ♣ Willow (*Salix exigua*, *Salix gooddingii*)
- ♣ Monkey flower (*Mimulus cardinalis*)
- ♣ Mequite (*Prosopis glandulosa*)
- ♣ Emory baccharis (*Baccharis emoryi*)
- ♣ Fremont cottonwood (*Populus fremontii*)

Species typical of drainages with dry washes or intermittent water are:

- ♣ Catclaw acacia (*Acacia gregii*)
- ♣ Baccharis (*Baccharis* spp.)
- ♣ Snakeweed (*Gutierrezia sarothrae*)
- ♣ Apache plume (*Fallugia paradoxa*)
- ♣ Utah agave (*Agave utahensis)*
- ♣ Mormon tea (*Ephedra* spp.)
- ♣ Four-wing saltbush (*Atriplex canescens*)
- ♣ Fremont cottonwood (*Populus fremontii*)
- ♣ Skunkbush (*Rhus trilobata*)
- ❖ Red-bud (*Cercis occidentalis*)

Upland species, described below, are also present in these dry or intermittent washes. Trees and shrubs tend to be scattered, but may also form dense thickets. Species composition varies depending on moisture availability, elevation, and geographic location in the canyon. Within the park, tamarisk occurs in the many of the side canyon and tributaries; however the distribution and density is highly variable.

The vegetation surrounding the tributaries is generally from desertscrub communities, which are composed of plant species from three of the four North American desert floras. The Sonoran desertscrub has the highest diversity of species. A two-season rainfall regime and lack of freezing temperatures characterizes the Sonoran desert (Warren et al. 1982). The Mojave desertscrub has higher local species diversity, but is primarily dominated by shrubs; characterized by winter rains and the absence of freezing temperatures (Warren et al. 1982). The Great Basin desert receives more winter rain than the Mojave, and frequently has severe winter freezes and the lowest diversity of the three (Warren et al. 1982).

The Great Basin desertscrub is dominated by big sagebrush (*Artemisia tridentata*) rabbitbrush (*Chrysothamnus* spp.), Mormon tea (*Ephedra* spp.) and a variety of perennial grasses. These associations are typically found in the lower portion of the canyon and comprise the vegetation surrounding some of the middle and lower tributaries. Typical Mojave desert species include blackbrush (*Coleogyne ramosissima*), turpentine broom (*Thamnosma montana*), bladder sage (*Salazaria mexicana*), and other species. The Sonoran desert species include brittle bush

(*Encelia farinosa),* catclaw acacia (*Acacia greggii),* ocotillo (*Fouquieria splendens*) and desert willow (*Chilopsis linearis*). Sonoran associations occur in the lower portion of the canyons, and many of these species can grow directly in drainages that are not frequently scoured.

Methods

SURVEY METHODS

Under this contract, crews completed tamarisk control work in more than 63 areas within Grand Canyon National Park. Project leaders selected the tributaries based on the numbers of tamarisk trees found during the preliminary surveys (i.e. feasibility of control at this time) and the extent of the seeps, springs, and riparian habitat found within the project areas. Prior to project initiation, crews conducted tamarisk surveys in all of the tributaries on the approved list (Table 9.1). Survey crews hiked as far up the tributaries as logistically possible and counted all tamarisk trees. Trees were broken down into the following categories:

Seedling	Newly emerged plants up to 1m tall
Sapling	Plants with less than 5cm diameter at the base of the trunk
Mature	Plants with greater than 5cm diameter at the base of the trunk, or with multiple branching at the base of the trunk

Note: The category of seedling does not adhere to the strict botanical definition, which means that the cotyledon is still attached to the emerging plant. For the purposes of the surveys, seedling denoted a plant that could be manually removed.

Survey crews also recorded ancillary data about the canyons such as general information about the canyon and access from the river. The surveys provided the baseline information necessary for determining trip schedules and logistics. Surveys revealed that the majority of the tamarisk trees that occur in side canyons were seedlings, which could be manually removed. The surveys and final project list are shown by River Mile below Lees Ferry (Table 9.1).

Table 9.1. Preliminary Tamarisk Surveys and Final Project List

			Tamarisk Size Classes					
River Mile	**River Side**	**Canyon**	**Seedling**	**Sapling**	**Mature**	**TOTAL Tamarisk**	**SW Willow Flycatcher Habitat Assessment Complete**	**Archaeological Resources Within 300m**
11	R	Soap Creek	2000	62	10	2072	X	X
20.5	R	North Canyon	2	7	16	25	X	
37.7	L	Tatahatso Wash	0	7	1	8	X	
39	R	First redbud alcove	19	8	8	35	X	
39.2	R	Second redbud alcove	0	0	6	6	X	
40.9	R	Buckfarm Canyon	5	5	14	24	X	
41.2	R	Bert's Canyon	0	0	8	8	X	X
56.2	R	Kwagunt Creek	8	35	5	48	X	X

57.5	R	Malgosa Canyon	0	0	80	80	X	X
64.7	R	Carbon Creek	47	49	54	150	X	
65.5	R	Lava Canyon	46	245	161	452	X	X
65.7	L	Palisades Creek	0	4	11	15	○	X
69.8	R	Basalt Canyon	1000	200	40	1240	X	X
74.1	R	74 mile Wash	0	4	0	4	X	
75	R	Escalante Creek	8	19	3	30	X	
75.6	L	75 mile Creek	697	65	14	776	X	X
81	R	Vishnu Creek	10000	71	44	10115	X	
84	L	Lonetree Canyon	130	8	21	159	X	
84	R	Clear Creek	2	4	14	20	X	
85	R	85 mile Spring	5	16	5	26	X	
88	R	Lower Bright Angel Creek	1000	131	135	1266	○	
91.6	R	Trinity Creek	30	101	38	169	○	
92.5	L	Salt Creek	0	0	4	4	X	
93.5	L	Monument Creek	87	74	245	406	X	X
94	R	94 mile Creek	155	202	238	595	X	
94.9	L	Hermit Creek	230	58	25	313	X	
96.7	L	Boucher Creek	40	100	40	180	X	
99	R	Tuna Creek	487	39	70	596	X	
105	L	Ruby Canyon	6	26	36	68	X	
106	L	Serpentine Canyon	0	10	38	48	X	
107.8	R	Hotauta Canyon	11	20	20	51	X	X
107.8	L	South Bass Canyon	3	19	20	42	○	X
111	R	Hakatai Canyon	0	0	100	100	○	
112	R	Waltenberg Canyon	12	20	11	43	X	
114.5	L	Garnet Canyon	10	118	25	153	X	
116.5	L	Elves Chasm	1	10	26	37	X	X
117	L	Bighorn Wash	100	47	14	161	X	
120	R	Lower Blacktail Canyon	40	0	4	44	X	X
120	R	Upper Blacktail Canyon	0	15	16	31	X	
122	R	122 Mile Creek	2	2	10	14	X	X
122.7	L	Forster Canyon	16	83	22	121	X	X
124.9	L	Fossil Canyon	4	10	25	39	X	X
128	R	128 Mile Creek	73	37	110	220	X	
129	L	Specter Chasm	14	35	1	50	X	
130.5	R	Bedrock Canyon	96	200	94	390	X	X
131.8	R	Galloway Canyon	10	34	118	162	X	X
132	R	Stone Creek	0	2	2	4	○	
133	R	133 Mile Creek	4	17	22	43	X	
138.5	R	Cranberry Canyon	9	24	3	36	X	
139	R	Fishtail Canyon	0	1	7	8	X	X
142	R	142 Mile Spring	0	12	2	14	X	
147.8	L	148 Springs	0	0	2	2	X	
147.9	L	Matkatamiba Canyon	500	0	4	504	X	

150	R	150 Mile Canyon	15	14	1	30	X	
152	R	Spring above 152 "Ledges Camp"	19	22	15	56	X	X
155	R	Slimey Tick Canyon	158	9	4	171	X	
155.5	R	Last Chance Canyon	32	14	2	48	X	
164.5	R	Tuckup Canyon	0	3	11	14	X	
168	R	Fern Glen Canyon	0	3	1	4	X	
171	R	Stairway Canyon	3	4	4	11	X	X
174	R	Cove Canyon - Lower	14	47	74	135	X	X
174	R	Cove Canyon - Upper	350	4	7	361	X	X
209	R	209 Mile Canyon	350	102	43	495	X	X
212	R	Bessie's Camp Creek	0	0	15	15	X	
214	R	214 Mile Creek	6	22	14	42	X	X

⭘ Southwest willow flycatcher habitat surveys will be completed in these areas before tamarisk control begins.

TAMARISK CONTROL METHODS AND CONDITIONS

The eradication methodology was finalized after all public comments were incorporated into the Environmental Assessment/Assessment of Effect (EA/AEF) document, which is required under the National Environmental Policy Act (NEPA) and the National Historic Preservation Act (NHPA). For this project, a combination of methods was used including mechanical, chemical, cultural (i.e. seeding), and other relatively new control methods. The methods selected for each project location were site specific and determined by the restoration biologist or project leader, i.e. adaptive. The following Integrated Pest Management methods were described for use in this project:

Manual Removal

This is the method used for seedlings and saplings in washes, streambeds, and non-sensitive areas. Crews use hand tools (i.e. picks, pulaskis, and shovels) to loosen the soil surrounding the plants and remove then the entire root system, or to at least below the root crown. Crews scatter the pulled plants on site, where they remain to decompose.

Garlon Lance Injection

The lance injector is a 1m long tool with four chambers. Small herbicide capsules (approximately 2cm long by 0.6cm in diameter) are placed inside the chambers, the lance is placed against the trunk of the tree, and as the top of the lance is pushed, the chamber opens and a capsule is inserted into the tree. The diameter of the trunk is used to determine the number of capsules inserted. The capsules are made of metal and should be removed after the herbicide gel inside the capsule is released into the tree, which typically take about 6 months.

Girdle Method (Hack and Squirt)

With this method crews used hatchets and hand saws to cut downward into the water-conducting tissue (phloem) of standing trees and then applied the herbicide mixture directly into the cut with a hand-pressurized sprayer equipped with a coarse spray nozzle. On larger trees, two or more cuts were often necessary. Based on input from other professional tamarisk crews, project leaders modified this method to include a complete girdle around the trunk of the tree.

Cut Stump

Crews cut the tree trunks near ground level with handsaws and then applied a 25% Garlon4® herbicide and 25% penetrating oil (JLB oil) solution to the cut surface and the sides of the trunk to ground level. The tree's phloem absorbs the mixture and transports it to the roots, with quick application increasing the effectiveness. Pressurized hand sprayers allow precision herbicide application with minimum overspray or drift risk. Crews extensively used this method alone, and in combination with girdling, achieving high rates of control success.

Basal Bark Application

With this method, crews treated the entire stem with Garlon4® (same mixture as above) from near ground level up to 1m, depending on the tree size. Crews applied the chemical mixture with hand held pressurized sprayers, which have small nozzles with coarse spray settings, allowing for direct spraying and minimal drift or overspray. This method is much less labor intensive, but is less effective on mature trees, so crews limited use of this method to smaller saplings and seedlings.

Combination Method

With this method, crews used a combination of girdling, cut stump and basal bark application. Crews primarily used the combination method in highly visible or sensitive areas.

Herbicide Use

The herbicide used for control was Garlon4® (triclopyr based), which is a general use herbicide, in a mixture of 25% Garlon4® and 75% JLB oil. Garlon3a® was taken on each trip to use directly next to water, but crews did need to use this herbicide, which poses slightly higher safety risks to applicators but less risk to aquatic organisms. One quart stainless steel sprayers, pressurized with bicycle pumps, were the herbicide application tool.

Pesticide certification is not required for Garlon® application; however, the park vegetation staff adopted the policy of having trained and certified applicators on site during application. During these trips, the project leader, all field crew leaders, and some of the volunteers possessed Arizona State pesticide certification. All project participants received herbicide orientation and training from the project leader. Project participants understood and abided by the established Personal Protective Equipment (PPE) requirements, the rules outlined in the safety plan for the project, and the job hazard analyses (JHAs) for exotic plant removal, herbicide application, boat travel, and backcountry camping. Rubber gloves, long sleeve shirts, long pants, and eye protection were part of the PPE necessary for herbicide applicators. Closed toe shoes, long pants, eye protection and leather gloves were the PPE required of all other project participants.

Project leaders followed all information and instructions on the herbicide label. All herbicide containers were leak- and spill resistant. All application equipment and chemicals were stored in sealed ammunition cans or large silver boxes during transport on rafts, and all storage containers had the product's specimen label and the Material Safety Data Sheet (MSDS) clearly displayed underneath a waterproof plastic sheet. The MSDS contains fire and explosive hazard data, environmental and disposal information, health hazard data, handling precautions, and first aid information. All trip participants reviewed the MSDS with the project leader and understood the first aid instructions described on the MSDS. One boat contained all herbicide and application equipment, herbicide containers, and PPE disposal containers, isolated from food and personal items.

Mitigation Measures

The following specific measures applied to all methods used for the project:

- Debris was disposed of to minimize visual impact (i.e. off trail, out of the drainage, covering cut stumps).
- Empty herbicide capsules were removed from trees in the year following treatment.
- Cut stumps were hidden from view to the extent possible.
- Soil was replaced and tamped down where manual removal was used to help minimize establishment of other invasive exotic species and to minimize visual impact.
- Tree cuts were made on tree sides least visible to backcountry users.
- When pruning, a minimal number of branches were cut to minimize visual impact.

Much of the debris remains on site to decompose and provide habitat for wildlife. Crews minimized the visual impacts of the project through carefully placed cuts and girdles and the combination of control methods employed at each project site. After the first two control trips, project leaders evaluated the success of the various control methods, which helped ensure greater control success.

Dates, Times and Conditions

In October 2000, crews installed photopoints and vegetation transects. Crews completed the tamarisk control work in October-November 2002 and 2003, and February-March 2004, with supplemental work funded by other sources during March, September and November 2003, and March 2004. Each fall river trip was 18 days long and consisted of 16 people. The trip length allowed for sufficient time to access and work in canyons on the itinerary. The goal of the control work was to target 15+ tributaries per trip, totaling the 63 canyons over the 4 control trips scheduled during the contract period. The fall months are ideal for tamarisk work since the trees are still actively transporting nutrients and water through the phloem and xylem, thus the insertion of herbicide into the tree yields effective control results. However, crews did complete supplemental project work in the spring, with good results.

Due to the remoteness of the terrain, it was necessary to access the majority of the project areas from the river, with the exception of Monument Creek, South Bass, Hermit Creek and Lower Bright Angel Creek, where crews were able to backpack into. Each of the fall trips launched from Lees Ferry and ended at Diamond Creek, with the exception of the October 2000 trip which proceeded, with shivering cold participants, all the way to Pearce Ferry due to the closure of the Diamond Creek road following a flash flood. On the fall 2002 and 2003 trips there were 16 participants and 5 rafts, on the March trips (supported by other funds) there were 18 participants (including two archeologists) and 6 rafts, and on the October 2000 trip there were 12 participants and four rafts. Backpacking trips into South Bass, Hermit Creek, Monument Creek and Bright Angel Creek occurred in February and March 2004. The strong volunteers not only carried their personal gear, but also strapped tools and project supplies to their backpacks.

On each river trip there was an exchange at Phantom Ranch, where new, invigorated volunteers arrived to assist with the project. Often, the upper half volunteers told horror stories about the long days and blisters, yet the newly arrived workers persevered and climbed into the rafts, waving goodbye to the previous group. On each trip, the workdays were extremely long, with coffee served between 6:00 and 6:30 a.m., and dinner often not ready until long after dark. Yet, on each trip, the participants enjoyed the project work, functioned as an integrated unit, and composed songs and stories about the work. The dedication and perseverance of all of the crew members was truly amazing and contributed to the overall success of the project. The hearty volunteers were absolutely crucial to the project accomplishments. Volunteers donated 800 hours in October 2002, 1005 hours in October 2002, 1248 hours in November 2002, 1620 hours in October 2003, and 959 hours in November 2003, 1000 hours in June 2004, 324 hour in March 2004 through backpacking trips, and more than 1000 additional hours on separately funded river trips supporting this project. In total, volunteers donated 7956 hours to this project during its first four years, a value of more than $115,000 dollars.

Table 9.2. October 13-31, 2000 Participant List

Role	Upper Half	Lower Half
Trip Coordinator / Project Leader	Lori Makarick	Lori Makarick
Head Boatman / Trip Leader	Dave Desrosiers	Dave Desrosiers
Boatman	Tim Stephenson	Tim Stephenson
Boatman	Matt Vandzura	Matt Vandzura
Boatman	Bryan Edwards	Bryan Edwards
Crew Leader #1	Rachel Stanton	Rachel Stanton
Crew Leader #2	Eric North	Chris Moore
Crew Leader #3	Fred Phillips	Fred Phillips
Cook / Worker	Simone Sellin	Simone Sellin
Volunteer	Kelly Burke	Kelly Burke
Volunteer	John Grahame	John Grahame
Volunteer	Roy Zipp	Boone Vandzura
AWPF Representative	Salinda Border	Dave Christina
Volunteer	Donna Koster	Donna Koster
Volunteer	Matt Gontram	Matt Gontram

Table 9.3. October 11-28, 2002 Participant List

Role	Upper Half	Lower Half
Trip Coordinator / Project Leader	Lori Makarick	Lori Makarick
Head Boatman / Trip Leader	Bob Dye	Bob Dye
Boatman	Kim Crumbo	Kim Crumbo
Boatman	R.J. Johnson	R.J. Johnson
Boatman	Alison Steen	Alison Steen
Boatman (volunteer)	Chris Louderback	Chris Louderback
Crew Leader #1	Kim Fawcett	Kim Fawcett
Crew Leader #2	Kate Watters	Kate Watters
Crew Leader #3	Fred Phillips	Anne Hadley
Cook / Worker	Simone Sellin	Simone Sellin
Archeologist	Lisa Leap	Regis Mayo
Volunteer	Kelly Burke	empty
Volunteer	Herman Griego	Bianca
Volunteer	Emily King	Steve Till
Volunteer	Donna Koster	Donna Koster
Volunteer	Matt Gontram	Matt Gontram

Table 9.4. November 8-25, 2002 Participant List

Role	Upper Half	Lower Half
Trip Coordinator / Project Leader	Lori Makarick	Lori Makarick
Head Boatman / Trip Leader	Bob Dye	Bob Dye
Boatman	Dan Hall	Dan Hall
Boatman	Alison Steen	Alison Steen
Boatman	Chris Louderback	Chris Louderback
Boatman (volunteer)	Matt Gontram	Matt Gontram
Crew Leader #1	Kim Fawcett	Kim Fawcett
Crew Leader #2	Kate Watters	Kate Watters
Cook/Worker	Simone Sellin	Simone Sellin
Volunteer	Rona Levine	Shawn Edwards
Volunteer	Monty Tillinghass	Steve Lomadafkie (tribal)
Volunteer	Beth Eisenberg	Beth Eisenberg
Volunteer	Donna Koster	Donna Koster
Volunteer	Sheila Yokers	Sheila Yokers
Volunteer	Anne Minard	Tom Schiavone
Volunteer	Margie Erhart	Empty

**Note: Anne Minard and Margie Erhart hiked out at Tanner, and Johanna Divine and Michael Whalen hiked in to take their places until Phantom Ranch.*

Table 9.5. October 3-20, 2003 Participant List

Role	Upper Half	Lower Half
Trip Coordinator / Project Leader	Lori Makarick	Lori Makarick
Head Boatman / Trip Leader	Jeri Ledbetter	Jeri Ledbetter
Boatman	Larry Stevens	Larry Stevens
Boatman	Alison Steen	Matt Dunn
Boatman	Kim Crumbo	Kim Crumbo
Boatman	Chris Louderback	Kate Thompson
Volunteer	Matt Dunn	John Sterling
Crew Leader #1	Kate Watters	Kate Watters
Crew Leader #2	Kim Fawcett	Kim Fawcett
Volunteer / Crew Leader #3	Johanna Divine	Anne Hadley
Cook / Worker	Simone Sellin	Simone Sellin
Volunteer	Jessica Cortright	Jessica Cortright
Volunteer	Scott Smith	Scott Smith
Volunteer	Heather Millar	Herman Griego
Volunteer	Kelly Watters	Kelly Burke
Volunteer	Dave Gentempo	Margie Erhart

Table 9.6. October 29 - November 15, 2003 Participant List

Role	Upper Half	Lower Half
Trip Coordinator / Project Leader	EMPTY	Lori Makarick
Head Boatman / Trip Leader	Dan Hall	Dan Hall
Boatman	Chris Louderback	Chris Louderback
Boatman	Alison Steen	Alison Steen
Boatman	Nicole Corbo	Nicole Corbo
Boatman	Michael Whalen	Rachel Schmidt
NPS Rep / Volunteer	Chad Olson	Dave Gentempo
Crew Leader #1	EMPTY	Kate Watters
Crew Leader #2	EMPTY	Kim Fawcett
Crew Leader #3	EMPTY	Angela Sokolowski
Cook / Worker	EMPTY	Simone Sellin
Volunteer	EMPTY	Willow Nelson
Volunteer	EMPTY	Chris Moore
Volunteer	EMPTY	Steven Till
Volunteer	EMPTY	Jessica Cortright
Volunteer	EMPTY	Beach Huntsman

Table 9.7. May 25-June 14, 2004 Participant List

Role	Upper Half	Lower Half
Trip Coordinator / Project Leader	Lori Makarick	Lori Makarick
Head Boatman / Trip Leader	Dave Edwards	Kim Crumbo
Boatman	Kristin Huisinga	Kristin Huisinga
Boatman	Kim Fawcett	Kim Fawcett
Boatman	Jessica Cortright	Jessica Cortright
Crew Leader #1	Kate Watters	Kate Watters
Crew Leader #2	Steve Till	Fred Phillips
Cook	Rachel Running	Rachel Running
Volunteer	Wendy Hodgson	Heidi Kloeppel
Volunteer	Frank Hays	John Randall
AWPF Representative / Volunteer	Reuben Teran	Amy Prince
Volunteer	EMPTY	Maddie Tighe

Prior to each trip, the project leader prepared itineraries, which were then reviewed and approved by park management. Poor weather conditions and additional time needed at specific sites necessitated the alteration of the itinerary on several occasions; however, in general, the well-designed project itineraries allowed ample time to complete project work. The final itineraries for each trip follow (Tables 9.8-9.12), with the exception of the October 2000 trip which did not have a formal itinerary to allow for flexibility in transect and photopoint installation. During each trip, there were only a few days of rain, with the exception of the October 2000 trip, which occurred during extreme weather and flash flooding events. Many of the project areas are in narrow side canyons, which are subject to flash flooding. On rainy days, crews only worked in wide-open canyons that would be safe during a flood event and minimized the use of herbicide.

Table 9.8. October 2002 Itinerary

Grand Canyon National Park / Grand Canyon Wildlands Council

Tamarisk Eradication Trip #1

October 11-28, 2002

DATE	CAMP	RM	PROJECTS
10/8-9			Food Pack - Simone, Larry, Kim F. & Lori
10/10	Lees Ferry		Meet at 8:45am at Larry's house in Flagstaff for departure. Once we are at Lees Ferry – rig the boats, have lunch, and spend time working on tamarisk treatment techniques.
10/11	North Canyon	RM 20.5 R	All people going downstream need to be at Lees Ferry by 7:30am for an 8:30am departure!!! We'll get to camp late – 20 mile river day! Get all tools and supplies ready for early departure up North.
10/12	Buckfarm Canyon	RM 41 R	North Canyon
			First Redbud alcove
			Second Redbud alcove
			Tatahatso Wash
10/13	Kwagunt	RM 56.2 R	Buckfarm
			Bert's Canyon
10/14	Kwagunt	RM 56.2 R	Kwagunt
1/015	Carbon	RM 64.7 R	Carbon Canyon
10/16	Basalt	RM 69.8 R	Palisades
			Basalt
10/17	Nevills	RM 75.6 L	74 mile wash
			Escalante
			75 mile Creek
10/18	Grapevine	RM 81.3 L	Vishnu Creek
10/19	Cremation	RM 87.2 L	85 mile spring
			Lonetree Canyon
			Clear Creek
10/20	Schist	RM 96 L	EXCHANGE DAY!!! Let's pick up the new folks and be heading downstream by noon. Orientation to the project for new folks, clean up coolers, organize tools, etc.
10/21	Slash/Parkins Camp	RM 108 L	Boucher Creek
10/22	Bighorn Wash	RM 117 L	Bighorn Wash
10/23	Stone Creek	RM 132 R	122 Mile
			Lower Blacktail
10/24	First Chance	RM 157.7 R	142 Mile Spring
10/25	No name	RM 185.5 R	Transit Day
10/26	Granite	RM 209 L	Transit Day
10/27	222 Mile	RM 222 R	Bessie's Camp Creek 212 R
10/28	Sus casitas		TAKE OUT!!!

Table 9.9. November 2002 Itinerary

Grand Canyon National Park / Grand Canyon Wildlands Council

Tamarisk Eradication Trip #2

November 8-25, 2002

Date	Camp	RM	Projects
11/6			Food Pack - Simone, Kate and Kim
11/7	Lees Ferry – We'll do dinner at VC or MC so		Meet at 9am at Larry's house in Flagstaff for departure (1705 N. San Francisco). Once we are at Lees Ferry – rig the boats, project orientation, etc.
11/8	Above Tiger Wash	26.3 L	LAUNCH!!!!! All people going downstream need to be at Lees Ferry by 7:30am for an 8:30am departure!!!
11/9	Malgosa	57.5 R	Malgosa
11/10	Malgosa	57.5 R	Continue work on Malgosa
11/11	Lava Canyon	65.5 R	Lava Canyon *CRF trip works with us
11/12	Lava Canyon	65.5 R	Finish Lava!
11/13	Phantom Ranch	87.2 L	Clear Creek *CRF folks will do the seedlings
			Lonetree
11/14	Trinity	91.6 R	EXCHANGE DAY!!! Head downstream EARLY!!!! Really.
			Trinity
11/15	Boucher	96.7 L	Finish Trinity in the morning
			Salt Creek (1 boat)
			Boucher
11/16	Waltenberg	112 R	Boucher – continue with this canyon *CRF folks work with us!
			Waltenberg Canyon
11/17	Upper Blacktail	120 R	Garnet
			Elves (may cancel this one depending on time)
			Upper Blacktail
11/18	Stone Creek	132 R	Forster
			Stone *CRF folks will do the seedlings
11/19	Across from Deer	136.2 L	Fishtail
			148 Springs (L)
11/20	Ledges	151.5 R	Matkatamiba (may cancel this on depending on time)
			150 Mile
11/21	Fern Glen	168 R	Spring above 152 at Ledges
			Fern Glen
11/22	Cove	174.3 R	Stairway
			Cove Canyon – Lower
			Cove Canyon - Upper
11/23	Parashant	198.5 R	TRANSIT Day
11/24	222 Mile	222 R	TRANSIT and clean up day!
11/25	Sus casitas		TAKE OUT!

Table 9.10. October 2003 Itinerary

Grand Canyon National Park / Grand Canyon Wildlands Council

Tamarisk Eradication Trip #3

October 3-20, 2003

Date	Camp	RM	Projects
10/1			Food purchase/pack and get boats loaded. Jeri/Matt will pack river equipment, Lori/Kim will pack tools/herbicide & deliver to Larry's, Simone/Jessica will be responsible for shopping and food.
10/2	Lees Ferry – We'll do dinner at VC or MC.		RIGGING DAY! Meet at 9am at Larry's house on N. San Francisco. Once at Lees Ferry – rig the boats, have lunch, and spend afternoon with project briefing.
10/3	Hot Na-Na area	16.4 L	All people going downstream need to be at Lees Ferry by 7:30am for an 8:30am departure!!! Really. We will stop at Soap and re-treat the trees there (just to the boundary).
10/4	Buckfarm Canyon	41 R	North Canyon (Team 1)
			First Redbud alcove (Team 2)
			Second Redbud alcove (Team 2)
			Tatahatso Wash (Team 2)
10/5	Kwagunt	56.2 R	Buckfarm (Team 1)
			Bert's Canyon (Team 2)
10/6	Kwagunt	56.2 R	Kwagunt
10/7	Carbon	64.7 R	Carbon Canyon - just to narrows
10/8	Lava Chuar	65.5 R	Lava Chuar
10/9	Lava Chuar	65.5 R	More Lava Chuar
10/10	Nevills	75.6 L	Basalt (Note - we'll have to prioritize today……)
			74 Mile Wash (Team 1)
			Escalante (Team 1)
			75 mile canyon (Team 2)
10/11	Cremation	87.2 L	Vishnu (Team 1)
			85 Mile Spring (Team 2)
			Clear Creek (Team 2)
10/12	Schist	96 L	EXCHANGE DAY!!! Let's pick up the new folks and be heading downstream by 11am. No tamarisk work today - but orientation to the project for new folks, clean up coolers, organize tools, and full orientation / training.
10/13	Slash/Parkins Camp	108 L	Boucher (Team 1)
			Tuna Creek (99 R) (Team 2)
10/14	Bighorn Wash	117 L	Hakatai 111 R
			Bighorn Wash (re-check if time)
10/15	Galloway	131.8 R	Specter 129 L (Team 1)
			Galloway (Team 2)
10/16	Fishtail	139 R	Cranberry (Team 1)
			Fishtail, camp (Team 2)
10/17	Tuckup	164.5 R	Tuckup
10/18	Parashant	198.5 R	Transit Day
10/19	222 Mile	222 R	Transit Day - See where others are camping, go low down. Start cleaning up supplies, coolers, etc.
10/20	Sus casitas		TAKE OUT!!! Wakey wakey!!!

Table 9.11. November 2003 Itinerary

Grand Canyon National Park / Grand Canyon Wildlands Council

Tamarisk Eradication Trip #4

October 29-November 15, 2003

Date	Camp	RM	Projects
10/27			Food purchase / pack and get boats loaded. Dan will be responsible for packing equipment, Simone/Kim will be responsible for shopping and packing all food.
10/28	Lees Ferry – Dinner in the big town!		RIGGING DAY! Meet at 9am at Can-ex. Drive to Lees Ferry – rig the boats. The upper portion of this trip will be dedicated to transit, so it will just be boatmen, 1 NPS representative.
10/29	Lone Cedar	23.7 L	Transit Day
10/30	Eminence	44 L	Transit Day
10/31	Carbon	64.5 R	Transit Day
11/1	Cremation	87.1 L	*Folks hiking in will arrive today by 3pm at Roy's Beach – 4pm briefing / dinner / orientation. People can go over to Phantom after that for phone calls, etc. - but we will not have access to the bunkhouse or other facilities. Note- Hikers meet at 411 S. Taber in Williams at 9:30 for ride to South Rim.
11/2	Granite	93.4 L	Trinity (Team 1)
			Salt (Team 1)
			Monument (everyone else)
11/3	94 Mile	94.3 R	94 Mile Creek
11/4	Slash Camp	108	Ruby
			Serpentine
11/5	Bighorn Wash	117 L	Hotauta
			Garnet
			Bighorn Wash - if time
11/6	Forster	122.7 L	Blacktail (Team 1)
			122 Mile (Team 2)
			Forster (Team 2)
11/7	Stone	132 R	Fossil (Team 1)
			128 Mile (Team 1)
			Bedrock (Team 2)
11/8	Stone	132 R	Stone Creek
11/9	Kanab Area	143	133 Mile Creek
			142 Mile Spring
11/10	Ledges	151 R	148 Spring
			Matkatamiba
11/11	Last Chance	155.7 R	152 Springs
			Slimey Tick
			Last Chance
11/12	Cove	174 R	Fern Glen
			Cove
11/13	202 Mile	202 R	Transit Day - Photodocumentation if time
11/14	223 Mile	223 L	Transit Day, Clean Coolers and Tools, etc.
11/15	YER HOMEYS		Wakey wakey eggs and bay-key!

Table 9.12. May-June 2004 Itinerary

Grand Canyon National Park / Grand Canyon Wildlands Council

Monitoring Trip #2

May 26-June 14, 2004

Date	Camp	RM	Projects
5/25	Lees Ferry		Meet at Larry's house at 8:30am, finish packing, drive to Lees Ferry, rig trip and have project orientation.
5/26	19 Mile L	19 L	Soap Creek
5/27	Tatahatso Wash	37.7 L	North Canyon, Tatahatso Wash
5/28	Malgosa	57.5 R	First Redbud Alcove, Second Redbud Alcove, Buckfarm Canyon, Bert's Canyon, Kwagunt Creek, Malgosa Canyon
5/29	Lava Canyon	65.5 R	Carbon Creek, Lava Canyon
5/30	Nevill's	75.6 L	Palisades Creek, 74 Mile Wash, Escalante Creek, 75 Mile Creek
5/31	Cremation	87.2 L	Vishnu Creek, Lonetree Canyon, Clear Creek, 85 Mile Spring
6/1	Salt Creek	92.5 L	Trinity Creek, Salt Creek
6/2	Ross Wheeler	107.8 L	94 mile Creek, Boucher Creek, Tuna Creek, Serpentine Canyon
6/3	Garnet	114.3 R	Hotauta Canyon, Hakatai Canyon, Waltenberg Canyon
6/4	Bighorn Wash	117 L	Garnet Canyon, Elves Chasm
6/5	Blacktail	120.1 R	Bighorn Wash, Lower and Upper Blacktail Canyon
6/6	Randy's Rock	126.5 R	122 Mile Creek, Forster Canyon
		122.7 L	Forster Canyon
6/7	Galloway	131.8 R	128 Mile Creek, Specter Chasm, Bedrock Canyon
6/8	Ponchos	137 L	Galloway Canyon, Stone Creek, 133 Mile Creek
6/9	Kanab Creek	143.4 R	Cranberry Canyon, Fishtail Canyon, 142 Mile Spring
6/10	No name	159 R	148 Springs, Matkatamiba Canyon, Spring above Ledges – 152 Mile, Slimey Tick Canyon, Last Chance Canyon
6/11	Below Lava	179.7 R	Tuckup Canyon, Fern Glen Canyon, Stairway Canyon, Lower Cove Canyon
6/12	Indian Canyon	206.6 R	Various Stops and Transit
6/13	216.4 Mile Camp	216.4 R	209 Mile Canyon, Bessie's Camp Creek, 214 Mile Creek
6/14	Sus Casitas		TAKE OUT, DE-RIG and CLEAN UP!!!!!!!!!

TAMARISK MONITORING METHODS AND CONDITIONS

As stated in the monitoring plan, vegetation cover data were used to determine the project success. The plan called for vegetation transect data collection in at least 25% (16 tributaries), providing an adequate measure of change in cover percentages. The location selection process, completed prior to the October 2000 trip, was random. Preliminary stratification of the tributaries, based on preliminary survey data, ensured the inclusion of an adequate sample of canyons with greater then 50 tamarisk and less than or equal to 50 tamarisk in the overall design.

The number of transects installed in each area was based on the extent of the tamarisk populations, with the goal of installing 1 to 3 transects in each area. The location of each transect was stratified so that populations of tamarisk would be bisected; therefore, the transect placement in each area was not random. Crews took Global Positioning System (GPS) readings and photographs at the start and end point of each 50m transect. The relocation of the transects was very easy and was accomplished with good maps that included the GPS points on satellite imagery along with a description of the transect.

Each transect was a 50m line, with crews using the point intercept method at every 0.5m (for a total of 100 hits) along the line. Crews used 2m long, 1cm in diameter pole as the point, with all vegetation, litter, brush, bare ground or water touching the point recorded. With this technique it is important to understand that it is possible to have greater than 100% cover when all the species are added together since there are often more than 100 total hits along each transect line. The following general categories and their attributes were used in data collection:

- Rock – Pieces of rock greater than 2cm to boulders or bedrock/schist
- Bare Ground - No cover on the ground to rock less than 2cm in diameter
- Brush - Dead vegetation larger than 2cm in diameter - primarily dead and down tamarisk in the transects
- Litter - Dead vegetation smaller than 2cm in diameter - primarily leaf litter and grass growth
- Soil Crust - Microbiotic soil layers
- Water - Differentiated into perennial and ephemeral

Analysis of Control Methods

Although current scientific literature documents successful control methods for tamarisk, refinement to the methods occurred during the work in Grand Canyon. Please refer to Appendix 9A for examples of methods and sample photographs, and to the fall 2002 and 2003 reports for preliminary discussion of methods (all appendices are located on the cd accompanying this report).

Crews used the Garlon lance injection method in 2002. Some benefits include increased safety for applicators, since there is less likelihood of contact with herbicide, and rainy conditions do not preclude the use of this method. When crews revisited Clear Creek in March 2003, the injected trees were still alive. Crews removed the capsules, and cut the trees. During 2003, 75 mile canyon flash flooded, and during the fall revisit, some of the injected trees were not located and likely had washed down the canyon. This was a significant concern since crews could not retrieve the empty capsules. Overall, crews found that the control effectiveness was low with this method and did not use it in 2003. However, park staff will further test this method in a controlled and easily visited setting and make a final determination about future use.

Crews used the hack and squirt method in 2002, but based on the control results and input from the Lake Mead Exotic Plant Management Team on the March 2003 trip, project leaders altered the technique prior to 2003 and renamed it the girdle method. Crews determined that it is necessary to cut into the outer bark (about 1cm deep) all the way around the tree trunk, leaving no section uncut. The cut can be lower to the ground that initially planned. Another key to the success is to spray the tree trunk from the cut to the ground in addition to herbicide application into the cut. Crews still use this method on scattered individual trees, but it remains difficult to use as the sole method in dense stands.

Crews now extensively use the cut stump method alone, and in combination with girdling, since the control results have been the highest. It is also easiest to retreat those areas. Crews did notice that on previously cut mature trees, the regrowth tended to be a basal cluster. The retreatment method for these clusters was basal application and no additional cutting was necessary.

Results

With AWPF funding the NPS and Grand Canyon Wildlands, assisted by hundreds of volunteers, treated 70,616 tamarisk trees in Grand Canyon National Park. Complete tamarisk treatment data for this project are found in Tables 9.13 and 9.14, and displayed in Figures 9.1, 9.2 and 9.3. Initial treatment work included 47,244 seedlings, 16,998 saplings, and 6,374 mature tamarisk trees, with a total of 1,406 saplings and 1,119 mature trees requiring some form of re-treatment, and 2,289 new seedlings pulled in previously treated project areas.

The total tamarisk canopy cover removed from the project sites was 40,804 square meters. In total, crews removed tamarisk from 1819 hectares (4496 acres) of infested land in 70 separate project locations. The approved project list included tamarisk control in 63 project areas, which was exceeded during project completion. The only project areas in which crews did not implement tamarisk control work by the time of this report were along Bright Angel Creek and in 150 Mile Canyon. However, crews supported by NPS funds will initiate tamarisk control along Bright Angel Creek on September 1, 2004. With AWPF project funding in the spring of 2004, crews installed 15 photopoints along Bright Angel Creek to prepare for the work. In such a highly visited area, Lori Makarick, the NPS coordinator for this project, decided to delay the implementation of work in that area until the fall, when visitation will be slightly decreased and large crews will have access to the NPS bunkhouse, also allowing additional project leaders to be trained and hired for such an extensive area. Crews did not visit 150 Mile Canyon due to logistical constraints and poor weather conditions during project implementation. While the approved tributary list for this contract includes these areas, this decision displays the NPS commitment to this project, and work will be well-underway prior to the end of this contract although numbers are not included in this report.

The amount of herbicide used, a mixture of 75% JLB Oil to 25% Garlon 4®, was surprisingly low over such vast acreage. Herbicide applicators used a total of 62.5 mixed gallons on all trips combined; this is equivalent to 15.625 gallons of Garlon4 concentrate and 46.875 gallons of JLB Oil. By using skilled applicators and direct target application methods a minimum amount of herbicide was required.

Crews completed follow-up control work in the majority of the project areas, yet in several areas, the preliminary control work required much more labor than predicted based on the tamarisk surveys. The following sites, due to extensive populations, weather, or lack of time, required additional visits and control implementation:

- Kwagunt Creek
- Carbon Creek
- Monument Creek
- 94 Mile Creek
- Boucher Creek
- Tuna Creek
- Fossil Canyon
- 128 Mile Creek
- Bedrock Canyon
- 142 Mile Springs
- 148 Mile Springs
- Stairway Canyon
- Cove Canyon

A large component of this project is long-term monitoring. On the first river trip (October 2000) participants installed the majority of the monitoring components. The components include vegetation transects and photopoints. On the fall 2002 and 2003 trips, crews installed photopoints in additional project areas, for a total of 376 photopoints and reference points installed. Please refer to the monitoring plan for the overall design and implementation scheme. Appendix 9B, *Project Photodocumentation,* contains a complete set of the project photodocumentation laid out for future field monitoring efforts, including pre- and post-removal photographs and photographs of the photopoints. Appendix 9C, *Project Photodocumentation Summary Table*, includes the summary data for all of the photopoints. Appendix 9A, *Representative Project Photographs,* includes examples of the various methods used during project implementation.

Appendix 9D, *Monitoring Transect Descriptions*, contains descriptions of each of the 22 vegetation transects and Appendix 9E, *Monitoring Transect Summary Data for 2000 and 2004*, includes all of the pre- and post-removal transect data. The results from the transect data showed tamarisk reduction by 100% from 2000 (before tamarisk removal) to 2004 (after tamarisk removal) in 20 of the 22 transects surveyed in canyons of Grand Canyon National Park (Table 9.15). Carbon 3 transect showed a 93% reduction rate and Last Chance 1 showed a 65% reduction rate in tamarisk from 2000-2004. For all 22 transects combined, the percent frequency of tamarisk before removal (2000) decreased 34-fold when transects were surveyed after removal (2004) (Figure 9.4). There was 35-fold higher mean tamarisk hits on the 22 combined transects before the removal (2000) than after the removal (2004) ($t= 5.143$, $df= 21$, $p<0.0001$, Figure 9.5).

The transect data also revealed that rock and bare ground were the most frequently occurring substrate type for the 22 transects combined in both 2000 (51%), and 2004 (61%) (Figure 9.6). The total vegetation hits in the combined 22 transects decreased by two-fold from 2000 to 2004. This reduction in total vegetation hits from 2000 to 2004 may be due to tamarisk removal, since tamarisk composed of 56% of the total vegetation of the combined 22 transects in 2000 and only 3% of the total vegetation in 2004.

When vegetation was categorized by growth form and combined, the data revealed that trees occurred most frequently (59%) in 2000 and grass occurred most frequently (43%) in 2004 (Figure 9.7). Again, the reduction in the occurrence of trees on the transects from 2000 to 2004 is likely due to tamarisk removal, a sign of success. A complete vegetation list for the species detected on the individual transects in 2000 and 2004 is in Appendix 9E, *Monitoring Transect Summary Data for 2000 and 2004*. Appendix 9F, *Plant List Summary Table for Selected Canyons*, contains more complete plant species list for a subset of the project areas. Appendix 9G, *Plant Lists for Canyons with Transects*, contains complete plant species lists for a subset of the canyons with transects.

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Table 9.13 Tamarisk Treatment Totals

	Treatment Method						Tree Size				
Canyon Name	Pull	Inject	Combo	Girdle	Basal Bark	Cut Stump	Seedling	Sapling	Mature	Cover (m2)	Area Infested (sq. meters)
105 Mile Canyon R	0	0	0	0	0	17	0	9	8	40	23200
122 Mile Creek R	2	0	0	10	0	3	0	3	12	19	96437
128 Mile Creek R	426	0	0	0	0	214	453	85	102	356	215212
133 Mile Creek	3	0	0	0	0	56	4	20	35	122	90456
142 Mile Spring	0	0	0	2	0	12	0	5	9	103	32224
148 Spring Above Matkatamiba	0	0	5	1	0	21	0	17	10	88	4463
152 Springs (combined with Ledges)	10	0	0	0	0	72	13	52	17	31	0
1st Redbud Alcove	0	0	0	0	0	49	16	27	6	62	18357
209 Mile Canyon R	8	0	0	0	5	155	9	109	50	393	124211
214 Mile Creek	3	0	0	0	0	40	1	32	10	62	59421
2nd Redbud Alcove	0	0	0	1	0	10	1	6	4	29	52663
75 Mile Creek	261	31	0	0	0	4	267	23	6	74	604040
85 Mile Spring	7	0	0	0	0	40	12	30	5	19	84108
91 Mile Canyon R	0	0	0	0	0	42	0	26	16	125	106260
94 Mile Canyon	67	7	0	0	0	662	41	439	256	1598	1110883
Basalt Canyon	4096	0	0	13	0	105	4093	57	64	452	470046
Bedrock Canyon	89	0	0	0	0	496	126	289	170	935	377162
Bert's Canyon	0	0	0	1	0	14	4	4	7	16	219823
Bessie's Camp Creek	0	0	0	15	0	13	1	9	18	127	60266
Bighorn Wash	193	0	0	52	0	19	223	21	20	135	66457
Blacktail Canyon - Upper	202	0	1	0	0	239	148	267	27	219	2754

Boucher Creek	5098	0	36	99	722	4757		7603	2424	685		3095	143133
Buckfarm Canyon	3	0	0	0	0	51		11	21	22		102	946707
Carbon Creek	1	0	0	18	0	208		5	49	173		1236	367949
Clear Creek	616	36	0	2	23	171		711	114	23		246	227837
Cove Canyon - Lower	33	19	0	192	0	186		7	214	209		853	180895
Cove Canyon - Upper	420	0	2	4	0	6		418	5	9		117	0
Cranberry Canyon	0	0	0	0	0	28		0	21	7		26	44069
Elves Canyon	147	0	0	0	0	49		148	18	30		287	70358
Escalante Creek	0	0	0	20	0	1		0	6	15		52	79750
Fern Glen Canyon	0	0	0	0	0	2		0	1	1		2	40721
Fishtail Canyon	0	0	2	2	0	5		0	5	4		35	47349
Forster Canyon	26	0	1	0	0	126		20	93	40		240	112792
Fossil Canyon	29	0	0	0	0	18		28	12	7		69	248531
Galloway Canyon	343	0	2	0	0	1150		641	462	392		1582	542214
Garnet Canyon	177	0	0	4	0	239		194	154	72		286	153778
Hakatai Canyon	8	0	0	0	0	83		8	54	29		118	33937
Hermit Creek	1870	0	0	0	0	1080		1935	728	287		1545	1064122
Hotauta Canyon	3	0	0	0	0	72		6	39	30		67	276634
Kwagunt Creek	503	43	12	71	145	3178		1748	1628	576		4915	1731154
Last Chance Spring	151	0	0	0	0	92		162	74	7		46	16635
Lava Chuar	100	0	59	33	174	2820		642	1790	754		5814	2340319
Ledges Spring	192	0	1	14	0	45		179	53	20		132	16536
Lonetree Canyon	53	0	0	14	0	214		146	109	26		233	106226
Malgosa Canyon	0	0	0	30	0	12		2	7	33		246	276535
Matkatamiba Canyon	1626	0	5	1	0	43		1439	224	12		1100	71939
Mohawk Canyon	6824	0	0	0	0	0		6824	0	0		750	89497
Monument Creek	2101	0	0	0	3115	5567		6992	3490	301		3014	484412
Monument Spr	50	0	0	0	0	0		50	0	0		10	54850

North Canyon	14	0	0	32	0	30		26	8	42		209	116095
Palisades Creek	0	0	0	0	0	20		3	2	15		59	162566
Rider Canyon	184	0	0	1	2	77		231	25	8		131	212736
Ruby Canyon	0	0	0	0	0	9		0	1	8		0	57827
Saddle Canyon	21	0	0	0	0	46		0	67	0		48	376193
Salt Creek	15	0	0	0	0	27		34	5	3		22	114105
Salt Creek Spring	20	0	0	0	0	0		20	0	0		5	154711
Serpentine Canyon	2	0	0	0	0	102		2	57	45		110	81984
Shinumo Creek	66	0	0	3	31	55		110	29	16		16	141583
Slimey Tick Canyon	2031	0	0	0	0	92		1919	188	16		103	96210
Soap Creek	0	0	0	0	3	40		10	10	23		56	127863
South Bass	2	0	0	0	0	0		0	2	0		1	28173
Specter Chasm	7	0	0	0	0	70		8	35	34		118	402022
Stairway Canyon	2	0	1	0	0	57		6	34	20		136	57577
Stone Creek	4289	0	0	0	103	2134		5467	1035	24		1277	576951
Tatahatso Wash	0	0	0	2	0	8		4	4	2		32	21042
Trinity Creek	44	0	0	0	0	301		137	161	47		261	263089
Tuckup Canyon	839	0	0	0	0	5		807	33	4		5	132248
Tuna Creek	31	0	5	0	14	625		241	344	90		878	84460
Unbar Creek	396	0	0	0	1	399		498	150	148		1327	971344
Upper Redbud	9	0	0	0	0	31		9	2	29		116	11461
Vishnu Creek	7	0	0	40	0	165		83	70	59		351	358507
Waltenberg Canyon	12	0	0	0	0	8		9	5	6		11	57944
NEW TREATMENT TOTALS	**33732**	**136**	**132**	**677**		**26787**		**44955**		**5255**		**36495**	**18194013**

TOTAL NUMBER TAMARISK TREATED 65802

Table 9.14. Tamarisk Retreatment Totals

	Treatment Method							Tree Size				
Canyon Name	Pull	Inject	Combo	Girdle	Basal Bark	Cut Stump		Seedling	Sapling	Mature		Cover (m2)
122 Mile Creek R	0	0	0	0	0	4		0	0	4		0
128 Mile Creek R	300	0	0	0	0	35		317	10	8		15
142 Mile Spring	0	0	0	0	0	4		0	0	4		21
148 Spring (Above Matkatamiba R)	3	0	0	0	0	14		0	1	16		59
1st Redbud Alcove	0	0	0	0	0	2		0	0	2		1
75 Mile Creek	7	0	0	0	0	1		0	6	2		9
85 Mile Spring	1	0	0	0	2	2		1	3	1		1
94 Mile Canyon	1	0	0	0	0	4		0	1	4		2
Basalt Canyon	0	0	0	0	1	21		0	8	14		85
Bessie's Camp Creek	0	0	1	0	0	7		0	3	5		148
Bighorn Wash	0	0	0	0	0	33		0	19	14		59
Blacktail Canyon - Upper	0	0	0	0	3	7		0	3	7		8
Boucher Creek	135	0	61	0	34	347		206	203	168		347
Buckfarm Canyon	0	0	0	0	0	1		0	1	0		1
Carbon Creek	1	0	0	0	0	8		0	2	7		25
Clear Creek	0	0	0	0	0	21		0	16	5		23
Cove Canyon - Lower	11	0	0	22	1	148		13	18	151		945
Cove Canyon - Upper	2	0	0	0	0	6		2	1	5		12
Fern Glen Canyon	89	0	0	0	0	0		89	0	0		4
Forster Canyon	0	0	0	0	0	60		2	43	15		42
Garnet Canyon	4	0	0	0	0	58		0	43	19		49
Hotauta Canyon	0	0	0	0	0	28		1	5	22		12
Kwagunt Creek	12	0	1	0	1	408		46	238	138		624
Lava Chuar	67	0	10	9	601	874		487	647	427		1081
Ledges Spring	0	0	0	0	0	4		0	1	3		1
Monument Creek	155	0	0	0	0	123		178	98	2		20
North Canyon	3	0	0	0	0	18		2	2	17		159
Ruby Canyon	0	0	0	0	0	11		0	0	11		6
Salt Creek	0	0	0	0	0	3		0	2	1		2
Slimey Tick Canyon	14	0	0	0	0	0		14	0	0		1

Soap Creek	0	0	0	0	0	7		0	1	6		3
Specter Chasm	313	0	0	0	0	0		311	2	0		5
Stairway Canyon	68	0	0	0	0	0		68	0	0		8
Stone Creek	547	0	0	0	0	8		540	13	2		334
Tatahatso Wash	0	0	0	0	0	1		0	0	1		7
Trinity Creek	0	0	0	0	0	15		0	10	5		8
Vishnu Creek	6	0	0	0	0	40		7	6	33		181
Waltenberg Canyon	5	0	0	0	0	0		5	0	0		1
RETREATMENT TOTALS	**1744**	**0**	**73**	**31**	**643**	**2323**		**2289**	**1406**	**1119**		**4309**

TOTAL NUMBER TAMARISK RETREATED 4814

Figure 9.1. Tamarisk Control by Size

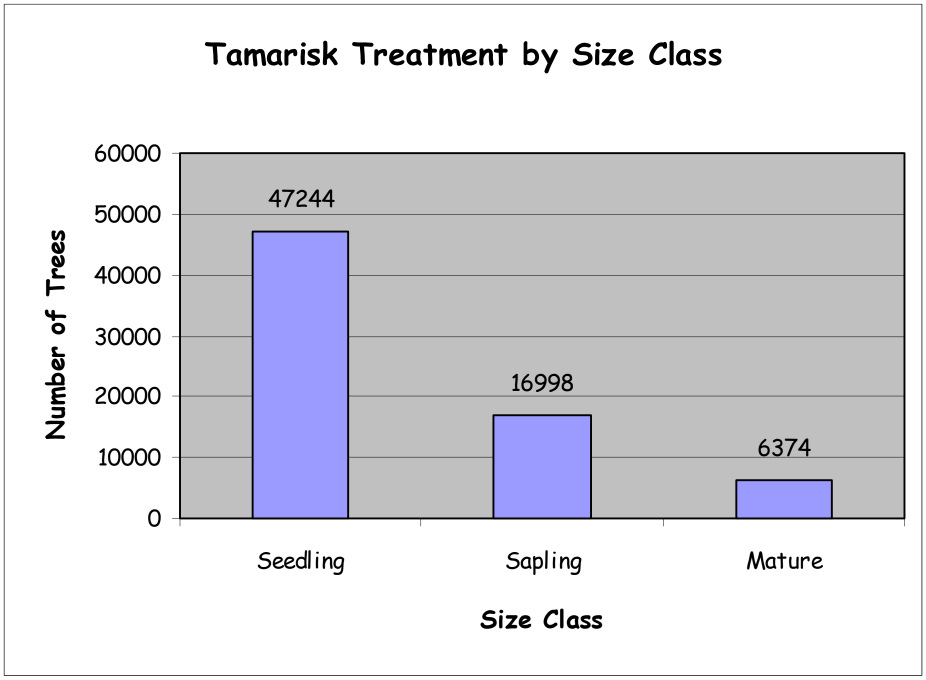


Figure 9.2. Tamarisk Control by Method

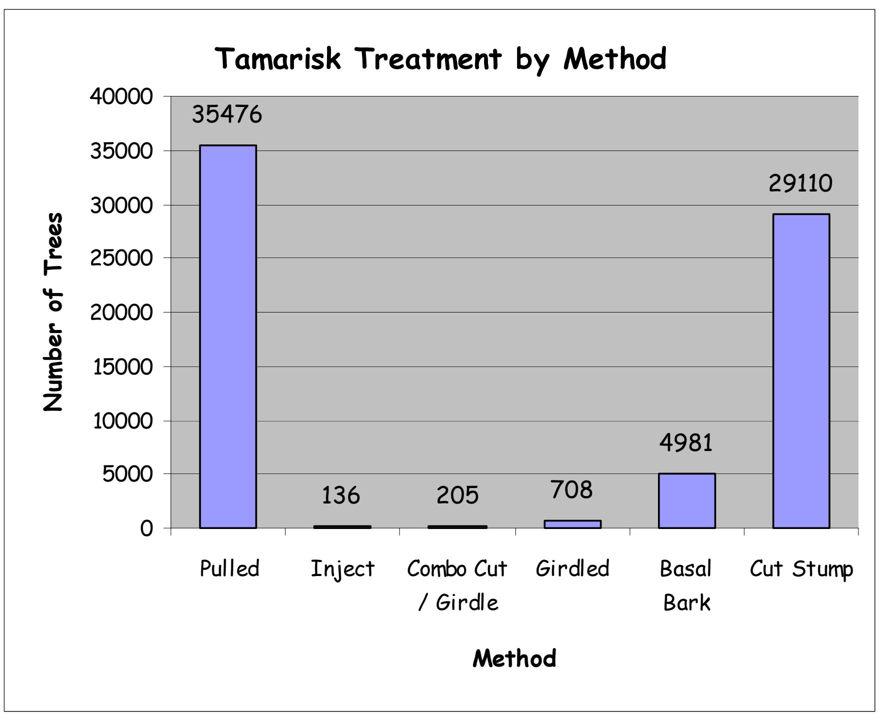


Figure 9.3. Tamarisk Retreatment by Size Class

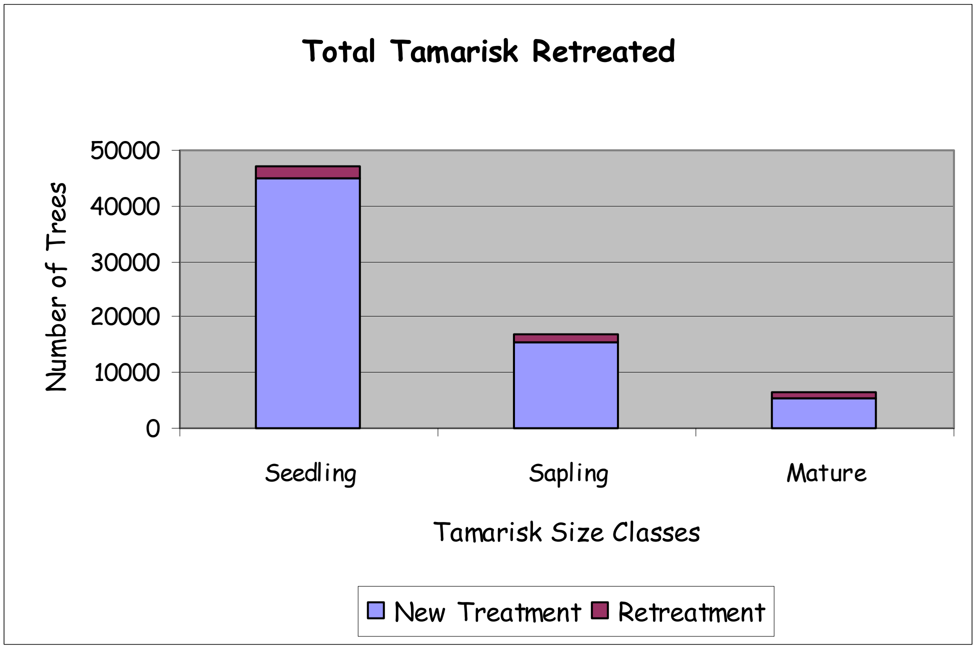
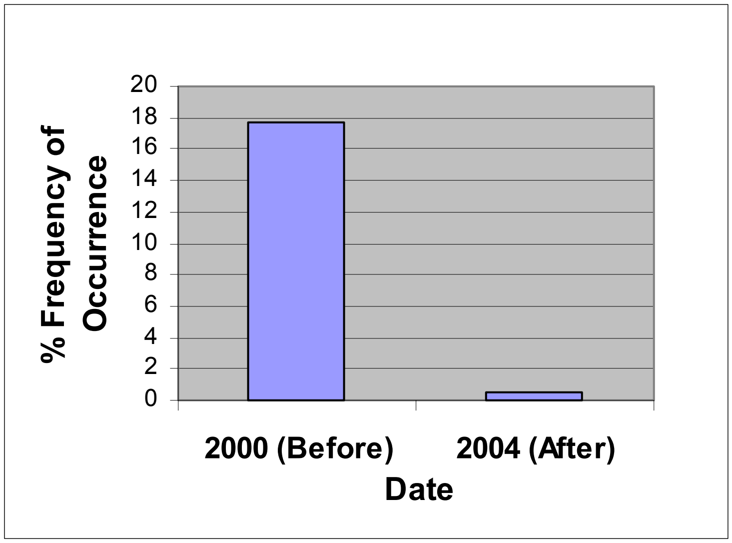


Table 9.15. Percent Tamarisk Reduction Rate 2000 to 2004

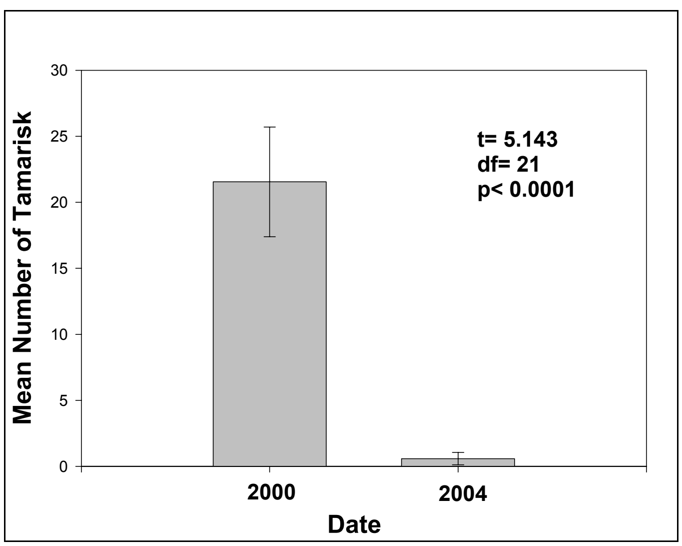
Transect	Reduction Rate (%)
Soap 1	100
Carbon 1	100
Carbon 2	100
Carbon 3	93
Lava Chuar 1	100
Lava Chuar 2	100
Lava Chuar 3	100
Serpentine 1	100
Serpentine 2	100
Hotuata 1	100
Waltenberg 1	100
Garnet	100
Elves Chasm	100
Bighorn Wash	100
Blacktail	100
Forester	100
Specter 1	100
Specter 2	100
Cranberry 1	100
Last Chance 1	65
Cove 1	100
Cove 2	100

Figure 9.4. Frequency of Tamarisk Before and After Treatment



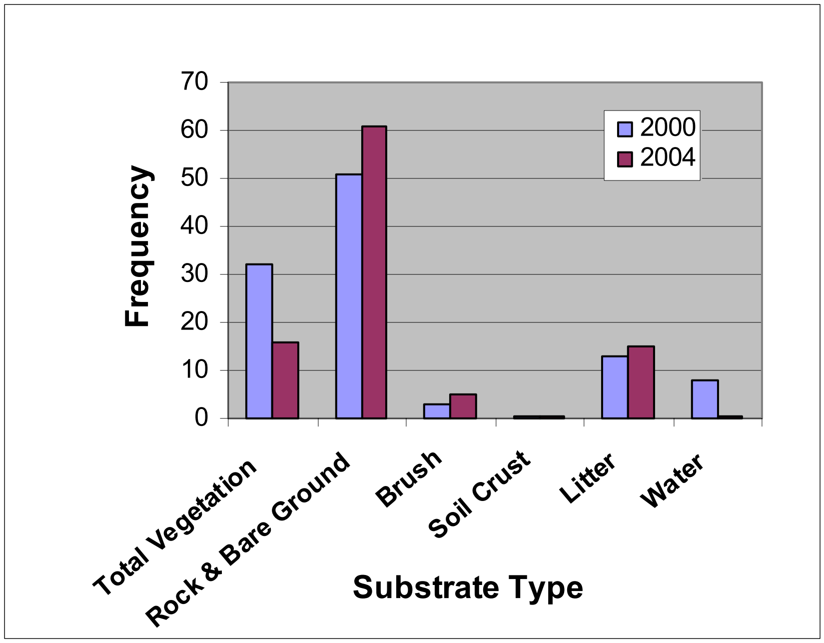
The frequency of tamarisk for total number of hits on 22 combined transects for before (2000) and after (2004) tamarisk removal for canyons in Grand Canyon National Park.

Figure 9.5. Mean Number of Tamarisk Before and After Treatment



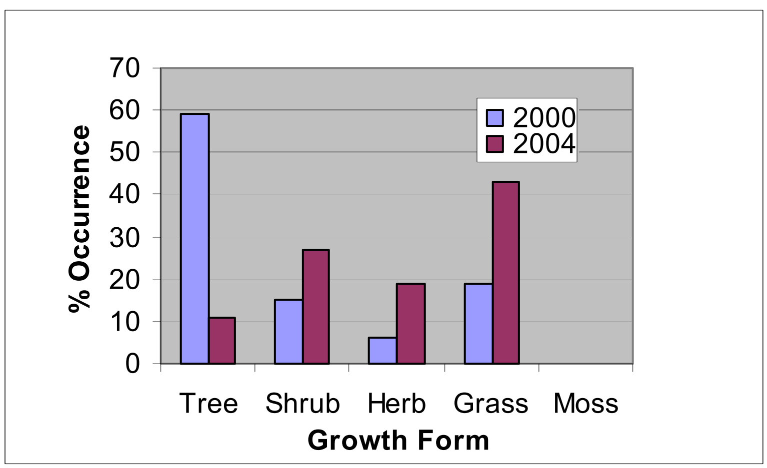
Mean number of tamarisk hits on 22 combined transects for 2000 (before tamarisk removal) and 2004 (after tamarisk removal) for canyons in GRCA. Error bars indicate standard error.

Figure 9.6. Substrate Frequency Before and After Treatment



Substrate frequency for hits on 22 transects combined in 2000 (Pre-tamarisk removal) and 2004 (Post-tamarisk removal) for canyons in Grand Canyon National Park. All vegetation detected on the transects is combined for total vegetation.

Figure 9.7. Percent Occurrence Growth Form Before and After Treatment



Percent occurrence of growth forms for total vegetation hits on the 22 transects combined in 2000 (Pre-tamarisk removal) and 2004 (Post-tamarisk removal) for canyons in Grand Canyon National Park.

Discussion and Conclusions

TRIBUTARY TAMARISK ERADICATION IN GRAND CANYON

Grand Canyon National Park and Grand Canyon Wildlands Council staff are extremely satisfied with the results of this large-scale invasive plant management and tributary restoration project. Preliminary survey results revealed 22,589 tamarisk trees within the scope of this project. During project implementation, crews removed 70,616 tamarisk trees from the project area, covering much more ground than project coordinators thought was possible. The retreatment data from the project area showed that only 7% of the initially treated trees required follow-up treatment (Table 9.16). With the refinement of control techniques, project coordinators anticipate the retreatment needs declining in the future as this project expands.

Table 9.16. Tamarisk Retreatment to Date – Percentage by Size Class

Size Class	# Tamarisk Retreated	# Initial Tamarisk Treated	% Retreated
Seedling	2289	44955	5.091758
Sapling	1406	15592	9.017445
Mature	1119	5255	21.29401
Total	4814	65802	7.315887

The project monitoring design objectives were to display: 1. How successful removing tamarisk from side canyons is in reducing colonization of tamarisk, and 2. How much and to what extent the native plant communities in side canyons recover and benefit from this removal. An acceptable goal was to decrease the tamarisk cover to 5% or less of the pre-management tamarisk cover in the project areas. The results from the transect data showed tamarisk cover and frequency reduction by 100% from 2000 (before tamarisk removal) to 2004 (after tamarisk removal) in 20 of the 22 transects installed in project areas. Only 2 canyons showed a lower rate of tamarisk cover reduction, one with 93% and the other with 65%. The project area with only a 65% cover reduction is a spring in the main Colorado River corridor and due to restrictions in the EA/AEF the project coordinator decided not to remove the tamarisk below the old high water line. Overall, the transect data reveal a very successful project. The project photographs provide supplemental support for the success of this project, with remarkable before and after tamarisk removal changes to these valuable riparian systems.

Public support for this project remains extremely high, another sign of a successful project. A vast cadre of individuals continues to want to donate their time and energy to this project. The project has been documented in the media, with the valuable support from the Arizona Water Protection Fund noted (refer to media materials included with the appendices at the end of this report). With Grand Canyon harboring some of the last remaining desert riparian areas, this project has gone a long way in protecting and restoring these valuable ecosystems.

RESULTS IN THE CONTEXT OF PUBLISHED STUDIES

Tamarisk is an aggressive species that has invaded riparian areas throughout the southwest and often dominates these areas. In addition to forming monotypic stands, biologist have identified many other possible undesirable attributes for tamarisk, including 1) crowding out native stands of riparian and wetland vegetation (Stevens 1990); 2) increasing the salinity of surface soil rendering the soil inhospitable to native plant species (Hem 1967; but not observed in Grand Canyon, Stevens and Waring 1987); 3) providing generally lower wildlife habitat value than native vegetation (Anderson et al.1977, Engel-Wilson and Ohmart 1978, Kasprzyk and Bryant 1989); 4) drying up springs, wetlands, riparian areas and small streams by lowering surface water tables (Robinson 1965, Weeks et al. 1987); 5) widening floodplains by clogging stream channels (Robinson 1965); 6) increasing sediment deposition due to the abundance of tamarisk stems in dense stands (Everitt 1980); and 7) using more water than comparable native plant communities (Carpenter 1998).

Because non-native plants have become an increasing problem in native riparian habitats, especially in the southwest, the development and implementation of weed management plans have become priorities in order to control non-native species invasion and prevent their introduction. The National Park Service (1990) outlined and defined five control strategies for invasive weeds, including: cultural, biological, physical, genetic, and chemical (herbicides). Later, the Nature Conservancy outlined five methods of effective tamarisk control, including: 1) applying herbicide to foliage of intact plants; 2) removing aboveground stems by burning or mechanical means followed by foliar application of herbicide; 3) cutting stems close to the ground followed by application of herbicide to the cut stems; 4) spraying basal bark with herbicide; and 5) digging or pulling plants (Carpenter 1998). The appropriate method is selected based on the size of the area of removal, chemical restrictions, native species presence, surface water presence, and available funding.

The most effective method for large monotypic stands of tamarisk (>2 hectares) is a foliar application of imazapyr (Arsenal®) herbicide to the intact plants or burning or cutting plants followed by foliar application of imazapyr or triclopyr (e.g. Garlon4® or PathfinderII®) to the resprouted stems (Carpenter 1998). This combination of methods has proven successful for large stands of tamarisk occurring in Afton Canyon, California (Egan et al. 1993), Anza-Borrego Desert State Park, California and Picacho State Recreation Area, California (Jorgensen 1996). However, the burn method by itself has not been successful because burning creates open areas which enables tamarisk to aggressively establish and out compete fire-intolerant native plants. Therefore, the cut-stump/herbicide method provides the most effective tamarisk control over long periods of time.

For modest-sized areas (< 2 hectares), the combination of cut-stump (physical) and herbicide (chemical) controls has been shown to be the most effective strategy for tamarisk control (Neill 1990, Egan et al. 1993, Hughes 1996, and Carpenter 1998). The cut-stump method involves cutting individual tamarisk plants as close to the ground as possible, and immediately applying the triclopyr based herbicides (e.g. Garlon4®, Garlon3a® PathfinderII®) to the cambium ring. Neill (1990, 1996) found that herbicides with triclopyr, appear to be the best choices for killing tamarisk due to higher phytotoxicity, low toxicity to humans, lack of restriction, and cost comparable to other herbicides when diluted as directed. The expected mortality with these herbicides is 95%, with lower mortality probably being the result of not cutting close enough to ground level and/or not treating the circumference of the stump completely (Neill 1990, 1996). Fall is the most effective time to treat tamarisk with this methods since trees are not producing seeds, entering dormancy and transferring reserves to their roots. This method was successfully applied in the Coachella Valley Preserve in California over a 5 year period that resulted in removing tamarisk from 7 ha. (17.5 acre) of wetland that had greater than 80% tamarisk cover over 70% of the wetland (Martin 2001).

Digging or pulling plants alone may be effective if the whole root mass is removed, otherwise re-sprouting is inevitable. Cutting tamarisk with no follow-up will not be successful, however multiple cuttings or burnings may kill the root system. (Luttrell 1983). Burke (1990) found that scraping a site along the shore of Lake Mead with a bulldozer killed some tamarisk plants, however many resprouted from roots that remained in the soil.

The primary methods used for the tamarisk removal effort in tributaries of Grand Canyon National Park included: manual removal for seedlings and the cut-stump/herbicide treatment for larger trees. These methods followed what the NPS identified as effective control strategies for invasive weeds, including physical (manual removal and cut-stump) and chemical (herbicide) control (NPS 1990). Also, because the proposed area of tamarisk removal in the selected tributaries was usually <2 hectares, tamarisk was integrated with native species in many tributaries, and the access into the tributaries was limited, the cut-stump/herbicide method outlined by The Nature Conservancy (Carpenter 1998) appeared to be the most favorable option. Crews conducted removal trips in October and November in order to coincide with the most effective time to remove tamarisk. The results reveal that tamarisk was successfully reduced, and in many cases effectively removed, in 70 tributary canyons of Grand Canyon National Park.

The cut-stump/herbicide method is very controlled, which is important for ecological systems that may have endangered or rare species present, such as MacDougall's flaveria (*Flaveria macdougalii*), southwestern willow flycatcher (*Empidonax traillii extemis*), and the Kanab ambersnail (*Oxyloma kanabense*) which occur or have been known to occur in Grand Canyon tributaries. Using these methods, herbicide application was limited and localized, preventing the herbicide from contaminating surrounding riparian vegetation, soil, and water. The Bitter Lake National Wildlife Refuge in New Mexico has also successfully managed small areas of tamarisk with the cut-stump/herbicide method in areas with endangered species present (McCown 1998). Overall, this project not only successfully controlled tamarisk in 70 project areas, but also ensured the continued protection of valuable ecosystems and overall biodiversity within Grand Canyon National Park.

Management Recommendations

During the implementation of this project, crews utilized and perfected tamarisk control methods in 70 areas within GCNP. Project leaders should continue to utilize these control and monitoring results to further refine project implementation, and continue to visit vegetation transects and project photopoints. The National Park Service (NPS) has an affirmative responsibility to protect and preserve the resources located within its units. NPS Management Policies require park managers "to maintain all the components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2001b). Park managers are directed to give high priority to the control and management of exotic species that can be easily managed and have substantial impacts on the Park's resources (NPS 1985, NPS 2001b).

This project verifies that the control of tamarisk in the park's side canyons and tributaries is indeed feasible. The effort thus far has set back the invasion of tamarisk into project areas by several decades. However, continued success requires maintenance since the seed source in the river corridor remains. A vast body of literature documents the impacts that tamarisk has on southwestern ecosystems, and Stevens (Section 3; 2001) summarized the impacts and ecology of the species. Since control is feasible and tamarisk poses a substantial impact on the resources located within GRCA, park management should continue and expand this work into other project areas within the park. Park management and the public have been very supportive of this project, and with continued documentation and successful implementation, that support should remain strong.

The EA/AEF for this overall project included three phases of tamarisk management and tributary restoration. The work completed under this cooperative agreement is Phase I of the overall project. With Phase I successfully complete, funding should be sought to continue this valuable project and expand into Phase II and Phase III project areas. The EA/AEF for this project states that the park will commit to the follow up control necessary for Phase I project sites, and this work (hand pulling seedlings) needs to be integrated into overall resource management in the park.

After completion of this report, NPS and Grand Canyon Wildlands staffs plan to summarize the results and prepare articles for both internal NPS publications and peer-reviewed journals. We recommend that the NPS continue to visit and re-read the vegetation transects every 3 years and retake photographs every year for a minimum of 10 years. NPS staff should also continue to recruit volunteers to assist with the follow-up maintenance needs (i.e. seedling pulling). The project mapping data should be displayed on the Park's website.

The funding provided by the AWPF has been essential to starting and making significant progress on this project—protecting and restoring the park's valuable riparian ecosystems. The AWPF were understanding of the delays due to the environmental compliance, and graciously allowed the project timeline to be altered to acquire all of the compliance and permits necessary to initiate the project. The partnership between GCNP, Grand Canyon Wildlands, and volunteers from the public has been integral to the success of the project, and all parties involved are commended for their dedication. Our primary recommendation is to continue the work, expanding the project to include all of the tamarisk populations in the side canyons and tributaries of the park.

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